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Ph. D. Dissertation: A DESIGN STRATEGY FOR HUMAN - SYSTEM INTEGRATION IN AEROSPACE:

Where to start and how to design Information Integration for Dynamic, Time and Safety Critical Systems

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Where to start and how to design Information Integration for Dynamic, Time and Safety Critical Systems

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Abstract

The aim of this research is to develop a framework that provides systemic design guidance for future interfaces that are to provide effective and cognitively suitable information presentation to operators in dynamic and time-critical domains. The aerospace domain has been chosen as the focus for this study.

In the aerospace domain there are numerous reported accidents where contributory factors are attributed to pilots' misunderstanding of automated system configurations, and pilots' misinterpretation of system behaviour. These problems have occurred as rapid advances in technology have led to an overabundance of 'useful' information being presented to the pilot. Currently, the information presented to pilots is often disjointed and distributed across various interfaces where each interface is based on its own design rationale. This creates problems where the pilot either cannot locate information in a timely manner, or misinterprets the available information. There is a need for a systematic design process that deals with meaningfully presenting the abundance of features and interactions of the new technology introduced into the cockpit through the use of existing domain knowledge, structures and strategies drawn from existing pilot training and experience.

The thesis is a case study. It shows how a new systematic interface design guidance process was developed by first identifying effective information presentation directly from airforce and airline pilots in their time-critical working environment conducted through observational and empirical studies. The studies provided answers for research questions that were concerned with finding appropriate information presentations for pilots. This resulted in a framework that serves as a guide for the interface designer on how to arrive at, structure and present information to an operator in a cognitively efficient manner.

The thesis demonstrates two applications of the design framework, one of which is then evaluated by pilots who demonstrate significantly improved speed and accuracy performance when compared to conventional alphanumerical displays. The applications and limitations of the framework are also discussed.

Chapter 1: The root cause of “tricky” cockpit displays

The subject of this thesis is a new systematic design approach for a modern automated cockpit that draws on the natural abilities and professional experience of pilots and so helps to deliver information to them in a meaningful way. This thesis aims to inform the design process of future systems through examination of how pilots use information in current and experimental automated cockpit displays. The aim of this research is to develop a framework that uses existing technology and operational practice to inform the design of future interfaces for effective and cognitively efficient information presentation to the pilot in a dynamic and time-critical domain.

Increasing levels of automation in modern aircraft and pilots being surprised by its actions have been linked to many incidents and several accidents (Funk & Lyall, 1998; Billings, 1997). Consequently, it is important and timely to assess the use of information and its presentation to the pilot in the cockpit. Despite the fact that Human Computer Interaction and Aerospace Human Factors has emphasized the need for the primary user of the system, the pilot, to be involved early in the design process (Billings, 1997; Preece, Rogers, & Sharp, 2002; Gagne, 1962; Kearns, 1982; Wiener, 1989), in practice, pilots are still involved late in the design process. Pilots participate mostly during evaluation of the finished design, where significant changes are costly and unlikely to be implemented (Figure 1.1).

The initial step towards a new design approach has been to elucidate the source of these problems through the examination of pilots’ basic training and operational rules that pilots use for rest of their career. Within this step observed and reported problems discovered during observation of pilots’ line operation (i.e. in a commercial airline operation), in manuals and training material were determined and classified, establishing the problem domain. Further, empirical steps then go on to examine pilots’ current strategies for dealing with the vast amount of information they are faced with.

Examination of pilots’ current strategies was accomplished through using a modified technique of acquiring information adapted from researchers who gained an insight into fire fighters’ cognitive process of decision-making (Omodei, Wearing, & McLennan, 1997). An evolutionary analysis was developed to reveal from real time data (i.e. pilots’ own-point-of-view video) the information required for future interface design. During the empirical study the analysis helped to bring to the surface surprising and unforeseen existing effective and robust information structures, operational rules and strategies that pilots use to acquire and process information in the glass cockpit (i.e. a cockpit equipped with Electronic Flight Instrument System, that looks like a panel made of ‘glass’, containing numerous computer displays, hence it is termed – ‘glass cockpit’).

The design framework was then developed based on the results of the empirical study. The framework considers established Human Computer Interaction design principles (Johnson, Johnson, & Hamilton, 2000) and work on task-related principles (Long & Dowell, 1989). Several candidate principles were identified that helped organize and structure information, and increase the usability of information for pilots’ in their time-critical and high workload environment. The framework was used to design two prototype interfaces, one of which was evaluated in an experiment run on pilots.

This chapter presents the background to this thesis research, identifies the problems that the research addresses and how these problems will be tackled. It introduces the systematic design approach that the research adopted, presents a brief statement of the research results and outlines the remaining chapters of the thesis.

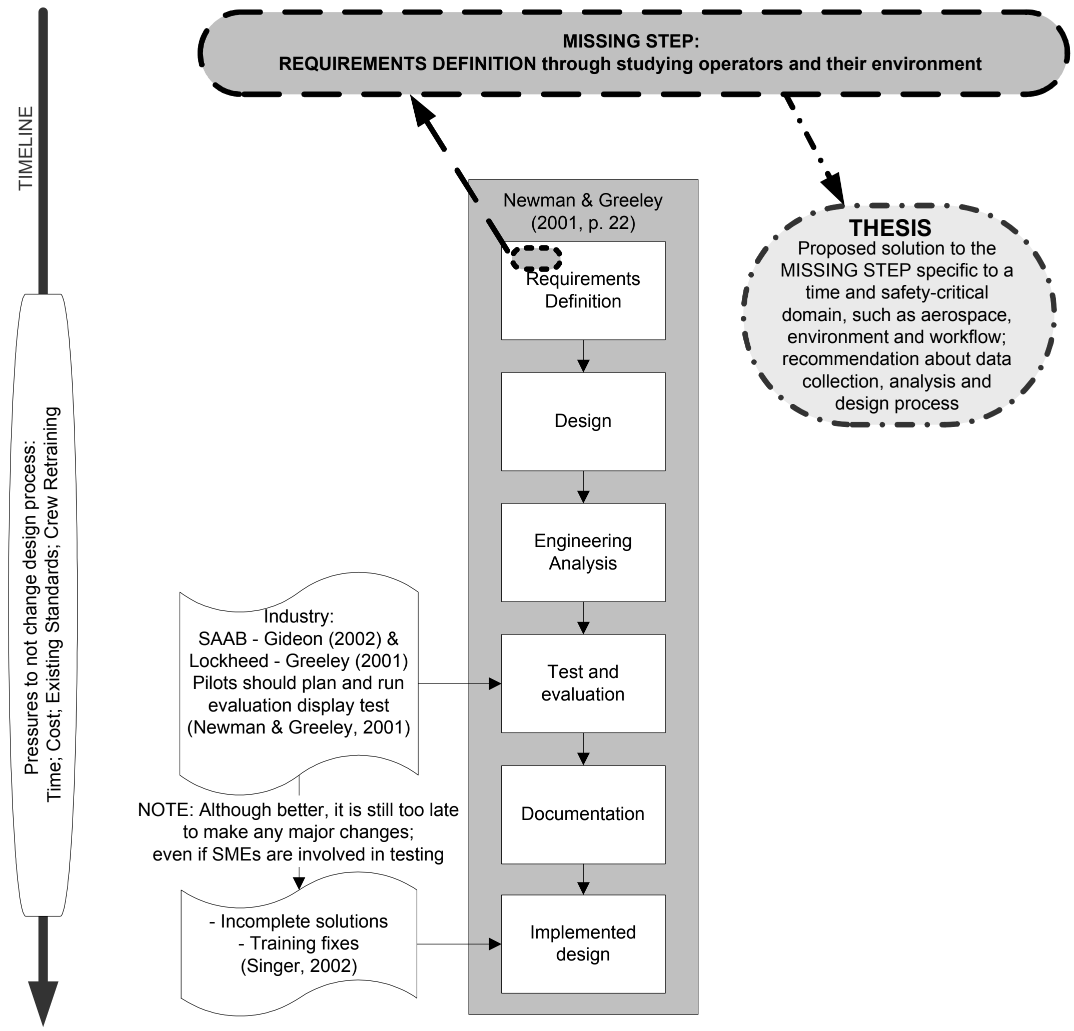


Figure 1.1: Missing Step in Aerospace Interface Design Process

1.1 Background

Due to fast technological advancements in the last century, aircraft cockpit development has swiftly moved from being: 1) designed by an engineer, who was often the test-pilot; 2) to an engineer who may have never piloted an aircraft. In turn aircraft operation has changed from being flown by a pilot, to being largely operated by automation and monitored by a pilot. Engineers who are involved in the design of modern cockpit interfaces are experts in technological advancements, but are less knowledgeable about aircraft day-to-day operation and the cognitive demands on the pilot. This gap in engineers' understanding (Newman & Greeley, 2001b) compromises the cockpit design process and affects pilots' understanding of aircraft operation leading to incidents and unfortunate accidents.

Information overload, especially during critical stages of flight (Billings, 1997; Dekker & Woods, 1999; Wiener, 1989), has become a critical challenge within the modern transport aircraft cockpit. Pilots are being stretched to their limits by the informational and computational demands of today's complex cockpit technology (e.g., Lintern, 2000 and Wiener, 1989). However, the problem is in poor organization and poor representation of information, rather than in the abundance of information that is presented to the pilot.

1.2 Thesis problem statement

Pilots' difficulties with automation have been in continuous discussion since the earliest implementations of advanced technology in the cockpit (e.g. Wiener & Curry, 1980; Wiener, 1989; Billings, 1997; Funk et al., 1998; Demagalski et al., 2002). Various studies have shown that the 'glass cockpit' (i.e. aircraft cockpit equipped with Electronic Flight Instrument System (EFIS) and Liquid Crystal Displays) aircraft can induce new types of errors (Sarter & Woods, 1992; 1994; 1995, 1997), but there has been relatively meager discussions of how these can be addressed. Clearly, it is not appropriate to revert to the old-style, pre-computer systems, but the manner in which the power of new technology is implemented into an interface remains a challenge for the field of Human-System Integration (Lintern, 1999) and this thesis.

It is argued that the incidence of errors within the glass cockpit is primarily an issue of information presentation and management. That is, a large amount of information is needed for the piloting job as a whole and pilots must be able to converge quickly on the constellation of information needed at any moment, rather than pilots merely requiring a large amount of information at any moment. Currently, information is widely distributed and poorly organized in the cockpit and poorly represented on the displays. Consequently, it is often very difficult to link information that must be associated and to maintain an appreciation of the state of dynamic processes with respect to different piloting tasks.

Although the problem is most visible during pilot interaction with automation through cockpit interfaces, the problem is actually rooted in the early stages of the design process (Figure 1.2). It is contended that problems start through an incomplete knowledge of pilots' operating practices leading to inaccurate specifications being generated the during requirement stage. This, in turn, affects composition of automation logic and information structure. Consequently, these flaws compound into the interface design stage, where flawed information is then transferred to the cockpit interfaces.

This research sets out to address these issues (i.e. issues of information presentation and management in a glass cockpit), carrying both theoretical and practical contributions to the field of Cognitive Engineering. The work reported here promotes the vision of a cockpit as a coherent and fully integrated information space. The approach for designing such a workspace is outlined using real world glass cockpits and commercial and airforce pilots. Further, the progress towards realization of that vision is outlined throughout the chapters (Section 1.6), including a description of knowledge elicitation techniques with the use of head-mounted-cameras on pilots, development of an evolutionary data analysis approach and the formation of the information systematization framework. Finally, the framework has a step-by-step description of how the two types of interfaces were designed, followed by the experiment where one of the interfaces is successfully tested on pilots.

1.3 Research questions

The work reported here was guided by four research questions that capture the fundamental concerns of the research. The first question looks at identifying problems pilots have with automation:

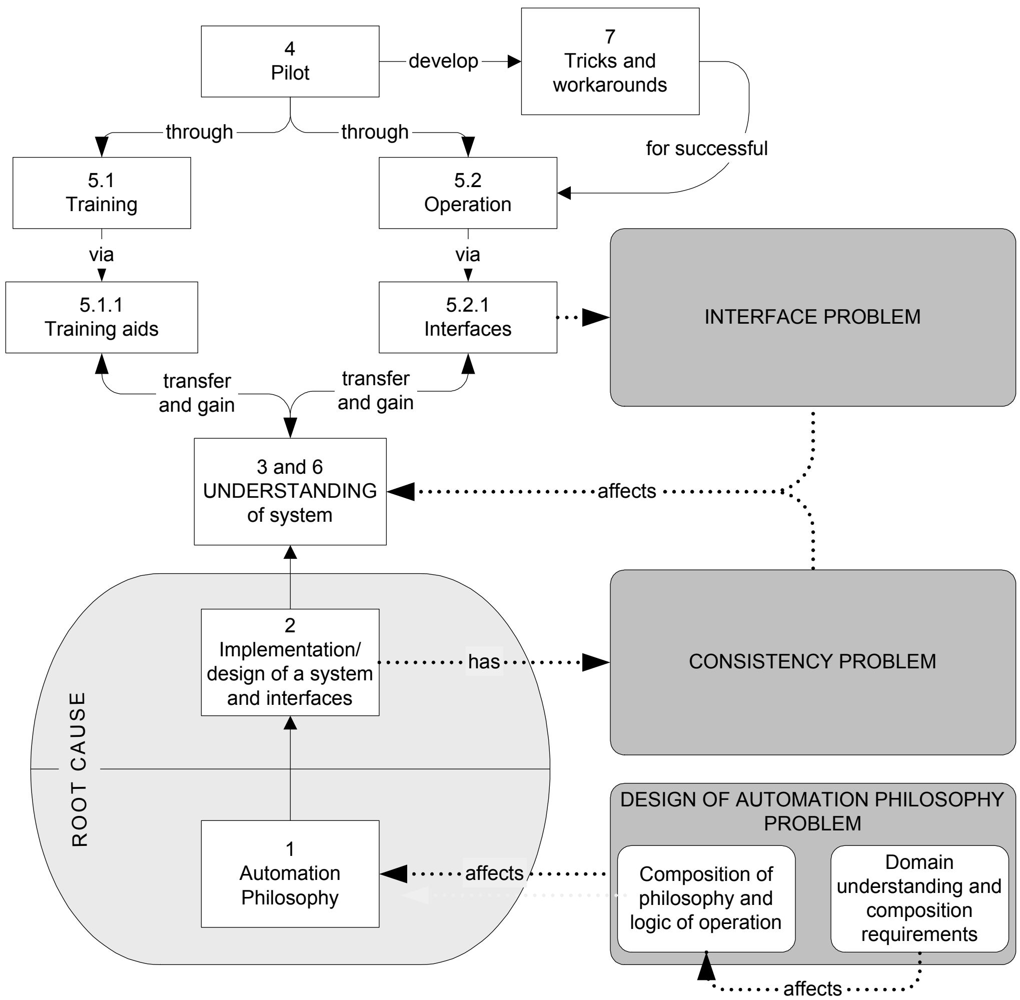


Figure 1.2: Root cause of glass cockpit problems

RQ1 - What are the root causes of the problems pilots have with understanding and operating automated systems?

In posing this question, the thesis considers how pilots are trained and acquire their understanding about aircraft operation and automation. Therefore, subsequently the problems that pilots encounter during training and operation are examined and classified (Chapter 4).

The second research question, tackled in chapter 3, is:

RQ2 - What is a suitable method for eliciting information about the knowledge of how pilots operate in a time and safety critical environment? And further, is there a method that can bring valid and reliable reports on pilots' own experiences?

The third question asked:

RQ3 - Is there a conceptual framework that helps designers and engineers compose and deliver effective information systematization and presentation throughout the glass cockpit and on individual interfaces?

In considering this question, it was necessary to question the sources of framework and concept formation (Chapter 5 and 6).

The fourth research question asks: could there be more effective ways of presenting information to pilots than currently used? In posing this question the consequent questions of:

RQ4 - What can provide more effective information presentation? and how can this be arrived at?

The latter question is described in chapter 6 and the use of the framework developed in the thesis to design interfaces is illustrated in chapter 7 and 8. Chapter 8 then examines the effectiveness of information presentation on a newly designed interface feature.

1.4 Research strategy

Aerospace Human Factors research has suggested several methods for effective cockpit interface design (Reising, Liggett, & Munns, 1999) where an eclectic team of specialists, ranging from pilots to mission specialist, designers and engineers are involved from the initial stages of design. However, (1) it is not practiced to the full extent in the industry as reported by several people involved in cockpit design (e.g. Singer, 2002). Stages in the design process and analysis are skipped, because a higher authority said "we did one once" before (Newman & Greeley, 2001b). (2) Simple involvement of future operators, such as pilots in this domain, and the rest of the team are not sufficient for a design of effective, cognitively efficient interfaces and automated systems. It is contended that, there is a need for a design strategy that can study, analyze, understand and translate the needs and wants of the operator to a designer and an engineer of the future system.

The thesis takes an eclectic approach borrowing, modifying and adapting stages from approaches that study operator's in similar environments. The domain is studied using a hybrid approach some of which is set in the field of ethnography (i.e. an observation study) and yet it has some laboratory-like settings (i.e. empirical study), such as in the field of psychology and human factors. The evaluation of the interfaces follows the Human Computer Interaction field of study. In addition to the above, the approach uses interview techniques often adapted by Human Computer Interaction and Cognitive Engineering. A cued-recall debrief method, based on own-point-of-view footage, is used to prompt pilots during a debrief-interview session to acquire an expert-knowledge. This method was originally used on fire-fighters to improve their training and study decision-making in a time and safety-critical environment (Omodei et al., 1997). The method had to be modified to suit the needs of this thesis to understand pilots' information needs and information use for the purpose of design guidance, which is described in chapter three and five.

The original data analysis used in the cue-recall debrief method (Omodei et al., 1997) was not suitable, as it suggested 'cognitive processes' as data categories (McLennan, Omodei, & Wearing, 2000). These categories were specific to the study of decision-making, which were not appropriate, because this was an exploratory study and should not have been assigned categories prior to viewing the data. Therefore, an evolutionary data analysis was developed. The data analysis is traced in a step-by-step fashion in chapter five. It revealed an 'Evolutionary Information Flow' used by pilots. This concept of information systematization and management was developed further in chapter six, using data described in studies (chapter three, four and five) and also using existing broader notions, such as metaphors (Lakoff & Johnson, 2003), frames of reference (Pinker, 1997), and visual cues in optical flow (Gibson, 1979) in fields of Human Computer Interaction, Sociology, Cognitive Psychology and Human Factors. All these inputs were employed in the creation of a 'Mind Reference Framework', which is later used to guide the design of the experimental interfaces.

The steps necessary to design an integrated information space are then described using some of the Human Computer Interaction, Human Factors and Cognitive Engineering interface design principles and guidelines. These are described and applied to design two interfaces in chapter seven and eight. One of the interfaces is later evaluated in the experiment, where pilots participated (chapter 8).

In developing an approach to resolve this information presentation and management problem, two studies of pilots' patterns of information use are drawn upon, (1) an empirical study of a *state-of-the-art* military cargo aircraft (Hercules C130-J), and (2) an observational study within the pilot training program for a modern, commercial aircraft (Airbus 320). The results of these studies are used to help identify the type of information pilots need and in what format they need it in order to manage a modern aircraft effectively.

1.5 Summary of results and contributions made

The problems that pilots reported to have with automation of flight systems are rooted in issues that Human Computer Interaction is established to tackle. The problems have been uncovered through observation of training, the analysis of documentation, empirical study and literature review (e.g., Sarter & Woods, 1994; Billings, 1997; Wiener & Curry, 1980; Funk & Lyall 1998). The problems pilots face are embedded in an ill-defined system, and interface information presentation is based on ill defined requirements (Figure 1.2). In existing systems the pilot, the domain and the nature of the operating environment are not studied together comprehensively enough to specify and define the final system design. Given the nature of the safety and time-critical operating environment in glass cockpit, novel approaches had to be adapted and developed to support system design.

This thesis represents a case study from examination of the problem to the potential design framework for new time and safety critical interfaces. A systematic design approach for an integrated information space was developed. The approach consists of studying the domain, by applying a novel elicitation technique (i.e. 'cue-recall-debrief' with use of head-mounted cameras on pilots) to obtain design requirements directly from the pilot. This is followed by the 'evolutionary' analysis of the data, which defines the Mind Reference framework of information systematization using the expert-knowledge of the domain. This is followed by practical interface design steps, based on the Mind Reference framework, indicating areas for the designer/engineer to examine to arrive at an effective presentation of information.

Finally, the resulting interface feature was tested on pilots, and these evaluations proved the resulting interface feature to be more effective than current alpha-numerical information presentation.

1.6 Outline of chapters

Chapter 1: The root cause of "tricky" cockpit displays. This chapter presents the thesis case, showing its' place in existing research. The second part of the chapter briefly outlines the content of the thesis (Figure 1.3).

Chapter 2: Gaps in the existing cockpit design process. The second chapter presents existing design processes, which are currently used in the aerospace domain. However, theoretical design processes that claim to be fantastic in application are seldom used in the aerospace industry (e.g. Newman & Greeley, 2001a). The frustration of test pilots is discussed who are often involved too late in the design process to make required changes. This chapter further sets the scene for the thesis, proposing how existing cockpit systems and operational practice can inform the interface design process during the early stages. The chapter concludes with a strategy of how this research is carried out.

Chapter 3: Identifying a suitable method for extracting and using the domain knowledge to inform the design process. The focus of chapter three is to identify a suitable method for evaluating pilots' information needs to inform future interface design. The cued-recall-debrief method (Omodei et al., 1997) is identified and justified. The preliminary study examined the suitability of the method and modified it for the purpose of this thesis. The suitability of the data collected during the preliminary study is examined after the data analysis.

Chapter 4: Defining the problems pilots have with information. Chapter four is the statement about refinement of the problem. The chapter describes how the researcher acquired the domain knowledge and captured existing problems in the domain. The aerospace domain was studied through personal experience and observation of pilots in training and during line (i.e. every day airline) operation. The problems observed and extracted from the available material, such as manuals, Standard Operating Procedure (Ansett Airlines, 2000) and Airlines' Computer Based Training (Airbus Industrie, 1997), are later studied and classified. Conclusions are then drawn about the challenges pilots' face in dealing with and understanding a vast amount of information, mainly in short periods of time, even during regular line operation, where highly sophisticated technology can often keep valuable information hidden or inaccessible to the pilot.

Chapter 5: Pilot's way of dealing with information challenge. Chapter five describes the empirical study, where a modified cued-recall-debrief method is applied in the full-flight simulator with participation of experienced pilots. The evolution of data analysis process is described in detail. The analysis process itself is unique and specific to the data collected. The remaining part of the chapter describes how the pilot makes sense of a vast amount of information in a short span of time. The structures of existing information presentation are shown that are currently used by the pilot. The strategies that the pilot uses to deal with information are drawn out of the data. Conclusions are drawn upon on how this data can be helpful in design of future interfaces.

Chapter 6: Building a Mind References framework. Chapter six summarises the results of the design process investigation that helped in understanding the pilot's information needs in the aerospace domain, such as the observation of pilots in training and during line operation, the study of operational material, and the empirical study of pilots in a full-flight simulator. The emerging framework for interface design is discussed from an ecological perspective.

Chapter 7: Using a Mind References framework to inform design. Chapter seven details how to apply the Mind References framework in the design of an interface. The step-by-step development of each feature on the interface is expanded upon.

Chapter 8: Experimental Study. This chapter describes the experiment that tests the interface feature. The interface feature evaluated is designed through application of principles based on the Mind References framework established in chapter six. The test was run on 40 experienced pilots. Four interfaces are compared, the interface feature that was designed through the application of principles proved to be more effective than a numerical presentation of the same data.

Chapter 9: Scope of the Mind References framework. The concluding chapter brings the results of observation study, empirical study and the experiment together, showing how these results answer four research questions posed earlier in this chapter. The results of how the systematic interface design process, the method used, and the resulting framework work together are discussed. The applications and limitations of the framework are drawn out. Lastly, possibilities for future applications of the framework and the systematic interface design process are discussed.

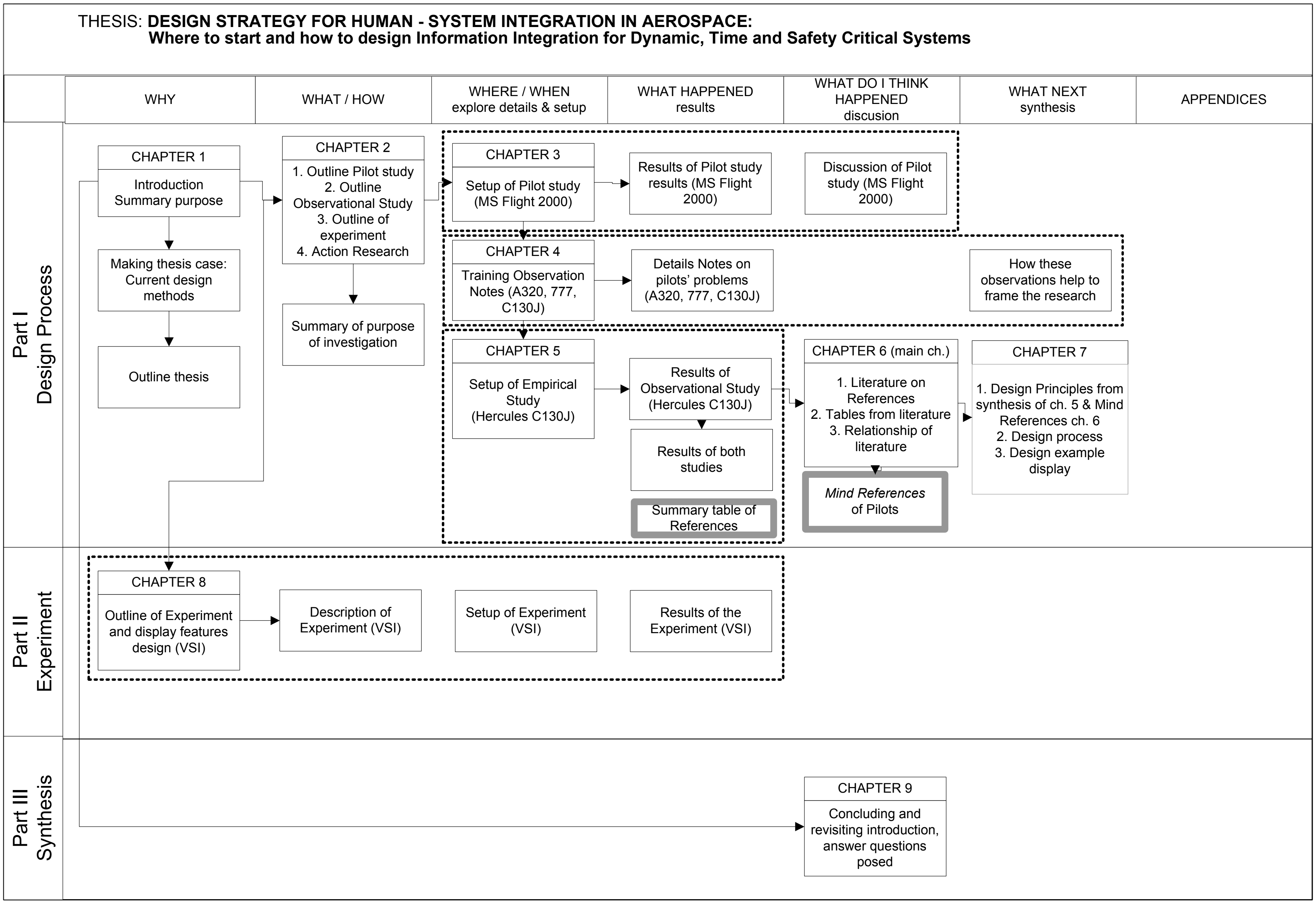


Figure 1.3: Thesis layout

Chapter 2: Gaps in existing cockpit design process

This chapter sets the scene for the rest of the thesis. It starts by examining the problem domain, by showing the human factor problems existing in the aerospace industry, evident from accident and incident reports. Then these problems are focused onto specifically understanding the problems that pilots have with automation in the cockpit. It discusses where automation was intended, and designed, to provide support in the cockpit. The root of the problems pilots have with understanding automation is then discussed, tracing this back to design (Figure 1.2 Root cause from Chapter 1). Existing theories of a possible relevant design process are examined, and practices in the industry are then scrutinized. The speed and pressure of evolution of the technology is then considered as a factor influencing decisions made in cockpit interface design.

Lastly, whilst referencing the existing design processes, the need for a novel approach that informs design, not only on *what*, but on *how* the information needs to be presented to the pilot, is outlined in a concluding part of this chapter.

2.1 What are the problems and what evidence exists?

The introduction of new technology to the cockpit has bought new demands on the pilot:

"…an operator must:

- *Learn and remember all of the available options.*
- *Learn and remember how to deploy them across a variety of operational circumstances, especially rarely occurring but more difficult or critical ones.*
- *Learn and remember the interface manipulations required to invoke the different modes or features.*
- *Learn and remember where to find or how to interpret the various indications about which option is active or armed and what are its associated target values.*

Note that modern technology not only creates these new demands but also holds the potential for supporting them effectively. However, this potential has not yet been realized as the ability of modern systems to preprocess, filter, integrate, or visualize information for the operator is not being exploited. System interfaces tend to be designed for data availability rather than observability. In other words, the amount of available data is sufficient and clearly exceeds that of earlier systems. However, the way in which data are presented does not match human information-processing abilities and limitations, and thus the burden of locating, integrating and interpreting these data still rests with the practitioner..."

- N. B. Sarter (p. 5, 2000)

The primary concern for those working in the area of flightdeck safety are the problems that pilots have with automation, where pilots are surprised by automation, and have difficulties knowing and understanding automation behaviour (e.g., Amalberti, 1999; Billings, 1997; Administration, 1996; Funk et al., 1998). This occurrence has been termed, an Automation Surprise. This also has been demonstrated by prominent researchers in a series of studies and surveys on the state-of-the-art, highly automated commercial aircraft (e.g., Johnson & Pritchett, 1995; Sarter & Woods, 1992, 1994, 1995, 1997).

These problems have been shown to have a number of potential causes, ranging from increasing autonomy and complexity of automation (Sarter & Woods, 1997), to the huge quantity of potentially relevant data presented throughout a modern flightdeck on various systems, screens, dials and switches (Sarter & Woods, 1995).
Previous studies have shown that, in a time and safety critical environment, such as aerospace, the usability and absence of relevant information can lead to undesirable decisions and actions on the part of the pilot. A poor understanding of both environmental data and automation activity has been a key factor in the build-up to major aviation incidents (e.g. Eldredge, Mangold, & Dodd, 1992; Owen & Funk, 1997) and accidents (Investigation Commission of Ministry of Transport of France, 1989; Aeronautica Civil of the Republic of Colombia, 1996; Ministry of Civil Aviation, 1990; Bureau Enquetes Accidents, 1992).

"Human failure plays a significant role in incidents and accidents" (Johnson, 2003), but as to how much of the reported statistic is actual 'human failure' and how much of it is induced by poor interface design is even harder to distinguish. It is similarly hard to determine how much of it is seeded in poor information presentation or the absence of information. Any statistic here counts towads human lives. Leading accident and incident investigators report that in aviation accidents between 1996 and 2003, based on United States National Safety Transport Board data, up to 44% of probable causes are human error (Johnson, 2004). Turning to more in depth studies of automation related aviation accidents, incidents and review of other related studies on automated aircraft (Funk, 1998):

- 23 % of problems and concerns (out of all problems in automated aircraft) are directly associated with "poor pilot/automation interface design"
- 14.5 % of other problems and concerns are associated with information problems pilots have related to the operation of the automation, where
    - 5.1 % automation behavior is unexpected or unexplained;
    - 4.2 % are understanding problems;
    - 2.7 % are standardization problems;
    - 2.5 % failure assessment is difficult.

To illustrate the seriousness of the problem and the significance of the statistics above, the results are broken down in one study included in the above statistics (Funk, 1998). The study (Sarter & Woods, 1997) was conducted by leading researchers in the area, Sarter and Woods, as a consequence to previous alarming studies (see Sarter & Woods, 1992, 1994). These studies revealed a major problem with pilot-automation interaction, or more exactly, pilots' poor understanding of the systems current and future status, the behavior of automation and inter-system relationships, which results in pilots being surprised by automation behavior, termed Automation Surprise. They devised open-ended questionnaires to study the notion of Automation Surprise based on specific cases, monitoring techniques and pilots' attitudes towards automation. The questionnaires were distributed to 750 line-pilots of the Airbus 320 aircraft (i.e. A320). Approximately 170 questionnaires were returned. The summary of the findings were the following:

≈ 20 %	Pilots failure to activate the approach (i.e. an automated function pilots rely on during last phases of fight);
≈ 20 %	Loss of constraints after entering change (i.e. change to automation function can override the limits preprogrammed to protect the aircraft);
≈ 13 %	Indirect mode transitions (i.e. the change of automation function without direct manipulation by the pilots);
≈ 10 %	Exceeded an airspeed of 250 knots below 10.000 feet;
≈ 5 %	Failure to understand automation strategies in managed vertical navigation;
≈ 5 %	Failure to immediately detect a failure of the flight management and guidance computer;
≈ 4 %	Unexpected airspeed during a go-around;
≈ 4 %	Decrease in airspeed when leveling off in the "open descent" mode.

The majority of pilots (80%) in the survey described above responded that they had experienced Automation Surprise at least once during line operation. Authors of the study reported that other studies on Boeing 757 and Boeing 737-300/400 confirmed this result.

The distressing conclusion about these data suggests that some pilots do not understand to the full extent and effects of automation behavior, and at times pilots' are not aware of the automation's actions and state. Furthermore, the current layout of information in the cockpit is not effective in helping pilots use and understand automation. The information in the cockpit is presented in a manner in which the pilot receives fragmented information about the environment and the aircraft state (Johnson & Pritchett, 1995; Sarter & Woods, 1995).

2.1.1 Automation is here to help…?

From the evidence above it is appropriate to query, why is the automation used in the first place? There must be a reason why it is tolerated despite it being a contributor to many deaths and problems in everyday operation of aircraft.

Automation was originally introduced for economic reasons (e.g., Wickens & Hollands, 2000; Newman & Greeley, 2001), such as the reduction of manpower, cheaper and more efficient aircraft operation and flexibility in all weather operation (Figure 2.1 Left hand side). Another reason for introduction of automation is to support human performance deficiencies (e.g., physical and cognitive limitations). However, according to current findings, automation does not necessarily help. It stretches the pilot's cognitive ability to the limits. Billings (1989), Singer (2002), Dekker and Woods (1999) assert strongly that automation creates new kinds of cognitive work, that appears to increase workload during critical situations and phases of flight, creating the potential for new types of errors (Woods et al., 1994).

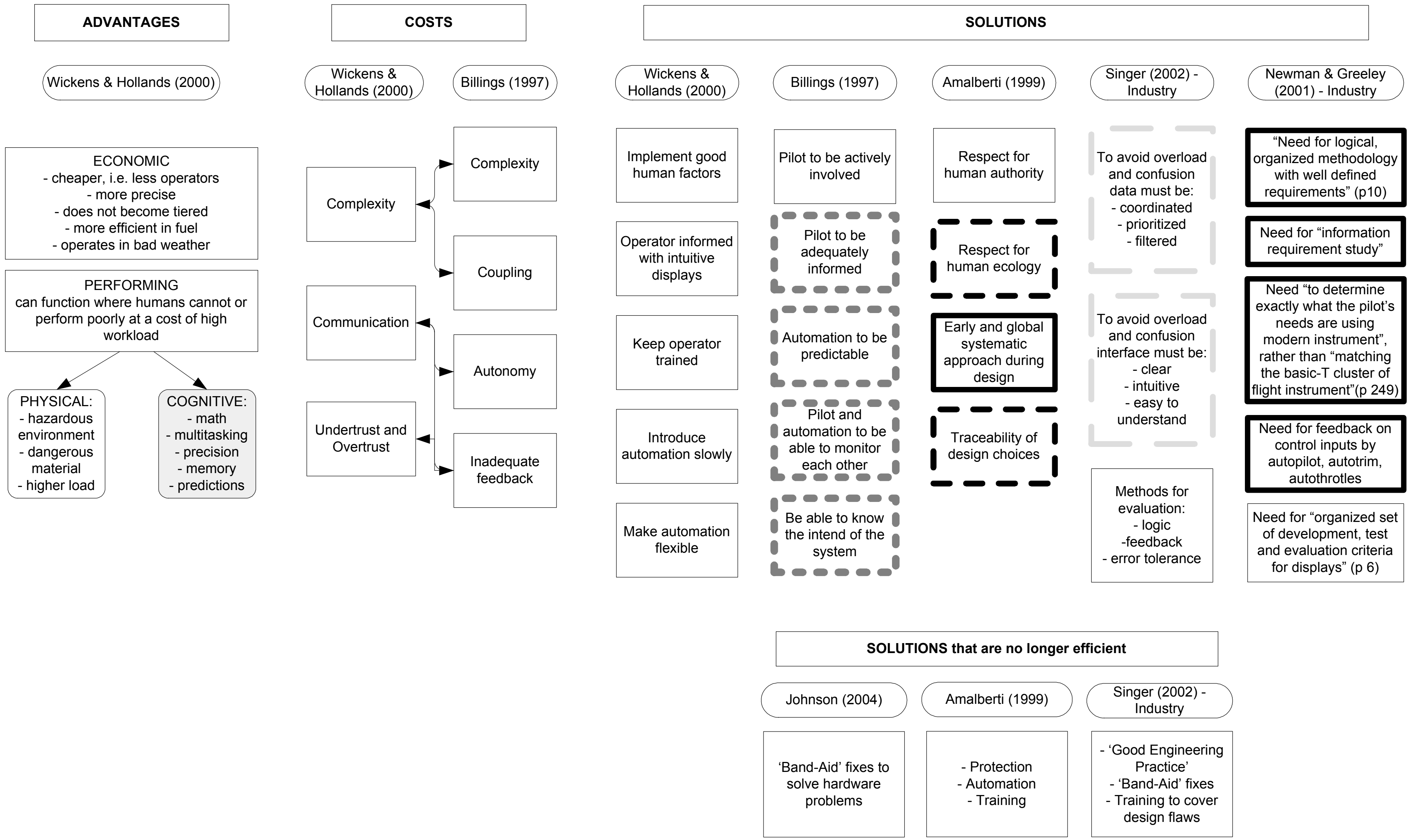


Figure 2.1: Automation Advantages, Costs and Solution

Automation comes at a cost (Figure 2.1 Costs) (Wickens & Hollands, 2000; Billings, 1997). Automation complexity increases. Links, relationships and interdependencies in the system (Billings, 1997) become difficult to understand both during training and during line operation. Autonomy (i.e. acting without the need of pilot's input - (Sarter & Woods, 1997) of aircraft automation increases to protect the crew, the airframe, and the engines. Who should have full authority over stressing or protecting the aircraft is still a debate between pilots and manufacturers (Newman & Greeley, 2001). It is debated on the issue that the pilot should decide the choice between hitting the ground or stressing the aircraft. However, current evidence (NASA and Lockheed Martin Aeronautical Systems - Newman & Greeley, 2001; Airbus - Tarnowski, 1999) suggests the manufacturers are winning, building in the protection in the control inputs and limiting the stress that can be exerted on the frame and the engines, without pilots being consulted about these decisions.

With increase of automation complexity and autonomy of automation, the gap of communication between the pilot and the automation is becoming greater. The feedback about automation actions and states is an area in which improvements can be made.

Solutions to these problems have been offered at several junctions, pilot training (e.g., Lintern, Roscoe, & Sivier, 1990), and changes to operating procedures that create workarounds to avoid the problems embedded in the design (e.g., Owen & Funk, 1997). However, solutions applied at the level of procedures, training and further automatic functions to avoid pilots being caught by flawed design, are not acceptable in the long term (Figure 2.1 Bottom), to be exact suboptimal design causes problems (Norman, 1986). For this approach has become a viscous cycle, starting at (1) poor design requirement level, (2) poor information management and its' poor presentation on interfaces, (3) training pilots to avoid being caught by embedded design flaws, (4) further implementation of modified operating procedures to fix recurrent mistakes that pilots make in everyday aircraft operation; and repeating it in (1) design of future systems using partial previous design requirements or reusing part of the system.

2.1.2 Design practice

Despite a variety of researched cockpit design approaches, guidelines and philosophies (e.g., Palmer, Rogers, Press, Latorella, & Abott, 1995; Wilkins, 1995; Storey, Rountree, Kulwicki, & Cohen, 1994; SAE, 1995; Dinadis, 2000; and Rasmussen, 1999), the design process in industry is constrained by: limited resources; regulations and restrictions of time and cost. As a result very little experimentation and testing are done to validate a new design (SAAB - Singer & Persson, 1996).

Newman and Greenly (NASA and Lockheed Martin Aeronautical Systems - Newman & Greeley, 2001) discussed and reviewed current practice in cockpit display design processes. They state there is a problem of bad design practices due to 'absence of logical, organized design methodology with well-defined requirements' (p. 10, Newman & Greeley, 2001). Manufacturers also report that they are aware of the design process being flawed (NASA and Lockheed Martin Aeronautical Systems - Newman & Greeley, 2001; Saab Aircraft -

Gideon Singer, 2002).

"Design decisions regarding cockpit interface have always been made based on subjective statements of the test pilot" (p. 16, Singer 2002). This practice is flawed because, although test pilots are often the most experienced pilots, they do not operate the aircraft in every day operation. Consequently, during test and "evaluation (test) pilots revert to previous experience that might not be relevant to the new design" (Singer, 2002). Newman & Greeley (2001) stress that test pilots should not be the sole decision makers. Instead they should input into an information requirements study to be conducted prior to requirements specification. The emphasis should be made on understanding the requirements of potential line operating pilots.

Another design process flaw, which is a common frustration to test pilots, happens during final testing phase of interfaces. Commonly, the full future system description is not finalized until late in the design process, but full functionality is not visible until final phase of testing, where often, despite test-pilots protest, the designs are approved as 'Good enough'. Often to change even a shape of the symbol is too costly in time and money (Newman & Greeley, 2001). As a result of flaws in the design process and poor design requirements, the cockpit design philosophy*, and the overall integration of new technology and information, is not always addressed due to already established ways of designing, as well as due to cost and schedule constraints.

2.1.3 Cost of 'good enough' design during every day aircraft operation

This chapter has introduced explanations for a range of problems in the automated cockpit that pilots have to deal with as a consequence of poor decisions made by manufacturers (e.g., poor system and information integration resulting in a pilot workload increase). The problems that this thesis is focused on relate to establishing information requirements and presentation. These range from missing information that should be available, but is either hidden behind several screen steps, or absent, to information integration problems throughout the cockpit and on individual screens and panels.

'Automated systems have made it really hard for practitioners (i.e. pilots) to pick up subtle changes in mode or status' of the system (p. 12, Dekker & Woods, 1999). In modern cockpits it is no longer possible to visualize the outcome of all automation mode input combinations. There are several levels of automation and "even though the primary logic is usually defined, many secondary effects might be overlooked" (p. 23, Singer, 2002). Supporting the understanding and detection of unexpected automation behavior, through automation feedback to pilots, has become a challenge for system designers (Sarter & Woods, 1997).

* Cockpit design philosophy is the overall application of a design rationale to the whole of the cockpit. For example, the 'dark cockpit philosophy' refers to the design of cockpit lighting, this philosophy provides significance to the 'off' condition as an indicator that the aircraft systems are operating normally, conversely only during abnormal conditions is the cockpit illuminated, hence, 'dark cockpit philosophy'.

The problems begins when an automated system's behaviour goes on unnoticed until it is too late to change it. "The introduction of FMC (Flight Management Computer – i.e. programmable automation behavior) has generated two types of side effects: (1) the consequences of errors has been shifted into the future and (2) (automation) aids can turn into traps" (p. 177, Amalberti, 1999). For example, in the Cali accident (Aeronautica Civil of the Republic of Colombia, 1996) early during the flight the pilot inadvertently, with help of an automated function to select the desired next point of the route, set an aircraft's course into mountainous terrain, which over a period of time led to a collision with a mountain. The accident report indicated that the aircraft's course into the mountain was not suspected by the pilots until the sound of an alarm by which time it was too late to safely escape from the collision into the mountain.

In a short description of the accident above both types of side effects are apparent. First, the pilot's selection of the next navigation point in the Flight Management Computer put the aircraft on a course for a future collision with mountainous terrain. Second, the automated navigation point preselection aid, by only requiring the first letter typed into it for entry from the pilot, led to the selection of the wrong navigation point. Here the automated function became a trap.

In the Strasburg accident (Bureau Enquetes Accidents, 1992) the first type of effect contributed to the accident, shifting the consequence of the command inputted by the pilot into the future. The pilot accidentally selected a high vertical speed of 3,300 feet per minute, rather than the intended 3.3 degree flight path angle, which would have been a more gradual angle of descent, but instead lead to unsafe high rate of descent.

The Strasburg accident brings another problem that pilots have to the surface, the sampling of information displayed (Bainbridge 1999). Pilots have to monitor preprogrammed automation behaviour, but the way the information is presented in the cockpit is not always suitable for a monitoring task. This problem occurs when the operator checks information less often than the information change occurs (Johnson, 2003), thus allowing information to change without their knowledge. In the dynamic aerospace environment, this can lead to devastating outcomes, such as in the Strasbourg accident in which the pilot believed a slower and less steep descent rate was entered, than actually was and failed to detect this through monitoring.

The pilots not only need to keep sampling information for changes they have inputted, but also need to maintain awareness of externally induced automation mode transitions, such as system status or behaviour change. Pilot monitoring tasks have become more cognitively demanding due to increasing autonomy of automation (i.e. it acts without the need of pilot's input) and automation authority (i.e. it can override pilot's command) (Sarter & Woods, 1997). Specifically, a change in automation mode can occur independently of immediate or direct pilot commands, it can occur due to a situation factor or protection limits preprogrammed in the system (Sarter and Woods, 1994).

Furthermore, apart from having difficulties understanding and monitoring automation in day-to-day operations, when pilots have questions regarding interface or automation functionality, they find it difficult to use manufacturer's manuals, and instead they revert to peer-to-peer network (e.g. the 'bluecoat' email group), for practical explanations. A recent study showed, that the reasoning in the manuals (i.e. instructing written material) used to explain automation logic and behavior is focused on the system states and not on an operational knowledge, for example, sequence of mode occurrence (Feary, Barshi, Sherry, & Alkin, 1999). Explanations provided in the manuals have an engineering perspective (Hutchins & Holder 2000), where data is detail-oriented, system-specific, and presented without a context from the broader flight situation (Baxter, 1998).

Based on the two discussed examples, of the multitude of other examined automation related accidents (e.g., Billings, 1997), and reviews of incident and research studies (e.g., Funk, 1998), it is concluded that there is a need to conduct a study and understand the information requirements pilots have. The empirical study within this thesis has to acquire: (1) an understanding of how pilots collect and (2) use the information; (3) what makes the process of understanding the current and consequential automation states and behavior comprehensible for pilots; (4) how to present information in more efficient ways than they are currently presented, as stated in the section 1.2, RQ2 and RQ4.

Consequently, the results of the empirical study are aimed to provide an information presentation format to help pilots build and sustain efficient understanding of what the systems is, how the system operates, and what is the systems next step going to be.

2.1.4 Is the root of these problems in design?

This set of problems appears to be deep rooted rather than superficial (Figure 1.2, Root cause). Not only is there evidence that pilots have difficulties understanding automation the manufacturers cockpit design philosophy (e.g. Tarnowski, 1999), by which the automation is programmed, is not followed through during the design process (e.g., Gideon Singer, 2002). This creates inconsistencies in the design of an entire cockpit.

Currently, there is no systematic design approach to overcome this problem of design inconsistency, no established framework to aid following through a coherent cockpit design philosophy. Current methods of managing the complex task of data and information presentation result in a vicious cycle. New systems do not take into account old problems and do not integrate old and new innovative technology. Instead both technologies are placed in one cockpit and are not checked if they are compatible or have the same philosophy behind their design.

In September 2004, Boeing proposed a new way of announcing information about automation modes. The proposed changes are at the implementation and the interface level (see respectively, Figure 1.2 Root cause, level 2 and 5.2.1) (Boorman & Mumaw, 2004), instead of at the cockpit philosophy level. They propose restructured mode presentation on the interfaces. First new and old tasks are identified for each mode, then they are organized on an interface according to function. If the function or mode is not used often enough it is put together with functions and modes that are displayed often. This eliminates the possibility that each function has it's own display that will not be used often and, therefore, the pilot may have difficulty finding the desired function when it is needed.

This is a good solution to allocate spatial properties to features of the interface, however, the initial considerations have to be done at the philosophy level, where functions and modes are considered taking into account pilots information needs in a view of dynamic aircraft operation, and the allocation of functions in the context of flight situations. It is contended that pilots' strategy of operating automation has to be considered first, during the requirements specification stage, which is earlier than the allocation of functions and modes to interface. Otherwise, by considering the allocation of functions and modes to the interface layout without overall cockpit design philosophy will cause problems later during training and line-operation at the level of comprehension for pilots (Level 3 and 6 in the Figure 1.2 Root cause).

Applying 'cockpit philosophy', means applying the same principles, rules and logic throughout the systems and interfaces from the initial stages of design through to implementation. Since the earliest implementations of automation, aerospace human factors have recorded a history of interaction problems in the cockpit (e.g., Wiener & Curry, 1980). Eventually, through incident and accident investigation individual problems are found and are given the recommendation to be fixed (e.g., Aeronautica Civil of the Republic of Colombia, 1996; Bureau Enquetes Accidents, 1992). It is contended that specifying and applying cockpit philosophy appears to minimize pilots problems of understanding the automation and to minimize the incidents and accidents as the problem is tackled at its root, at the philosophy level and consistently throughout the cockpit design (Level 1 Figure 1.2 Root cause).

2.2 What methods are available and useful for the purpose of the thesis

Solutions to existing problems need to be applied at the requirements definition stages, which is evident in the following quote (see the darkest grey in Figure 2.1 Automation Advantage, Cost, Solutions) (Newman & Greeley, 2001; Amalberti, 1999). "The level of dependency between sensors data, logic and display is very high and requires a very systematic approach" (Singer, 2002). Currently, there is a need for a systematic design approach that will identify the information needs of the pilot. It is emphasized by cognitive engineers that human cognition has to be, and can only be, studied in the context of real work carried out in a real environment by professionals (Billings, 1997; Hollnagel, 1993; Rasmussen, 1988; Reason, 1990; Woods, 1993). Therefore, this approach should rise from information requirement studies using line-operating pilots and the latest technology to design for more efficient pilot and system integration.

There is a need to determine the exact information needs of pilots, how pilots use information, how pilots currently identify automation behaviour and states, and identify what strategies pilots use to operate automated aircraft. This needs to be based on real-world observation. It is important to identify the workarounds that pilots' adapt, and from this gain understanding of how best to support pilots' activities and present information to pilots. For example, Hutchins (1995) writes about pilots applying their own strategies to create shortcuts in mental calculation, through using features of the display that are not designed for that task (Hutchins, 1995). If new design logic is applied to automation (i.e. rules to which automation complies) without considering the natural strategies that pilots already use, we are likely "to design out robust strategies (that pilots use) out of the new systems that can also save time for designers and future mental effort for pilots" (p. 343, Lintern 1995).

As previously stated, pilots are involved too late in the design process, when it is too late to make any major change that they might require. Despite the fact that one of the perceptions among engineers, 'ask one pilot and you will have three opinions', there is a need to include pilots and subject-matter-experts, in the design process, since they are *the operators and users*. The questions are when in the design process, and how, to elicit knowledge from subject-matter-experts in a useful form for engineers and designers. There is a need to identify pilots' strategies and the information that they use to understand automation in an environment most close to their real-world operating environment and apply these findings in future designs.

2.3 The real world study

Chapter three identifies suitable information-elicitation techniques that can be administered in a time and safety critical environment, such as aerospace. The pros and cons of the technique are weighed and addressed in a preliminary study on pilots, to identify whether this technique is suitable for the elicitation of pilots' knowledge. Data from a participant is analyzed to determine the appropriateness and quality. Finally, this data is used to inform an initial display design and preliminary conclusions are drawn about pilots' information needs in preparation for a fuller empirical study.

The study aims to identify how pilots assimilate information about a forthcoming task, how they construct information to perform the task through use of available information. This data is required for the development of design principles that can be applied to the design of a prototype interface feature. This interface feature will be designed to help the pilots to perform the forthcoming task through the effective presentation of information and use of automation. It is intended that the interface feature be designed in such way that it will enhance human abilities, rather than add work and contribute to error.

Chapter 3: Preparation for an Empirical Study

3.1 Introduction

As suggested in the previous chapters, there is a step (Figure 3.1) in the current process of aviation interface design that is not practiced and it should be. This step is about obtaining information prior to the definition of the requirements *from the pilots* themselves about *what* the pilot needs to have on the interface to use the system effectively and with ease. Additionally, it will become apparent that using this step can simultaneously inform design, bring ideas of *how* to present information to pilot, which is discussed in depth after the empirical study.

It has been suggested that design process of pilots' workstation needs to include the crew in the preliminary stages of design (Gagne, 1962). In 1980ies Kearns (1982) suggests the order of design stages, and the second stage after mission analysis, is a preliminary design stage that *should* include a team of specialists, including the pilot. However, these approaches suggest that the crew will be included as part of the design team only, rather than using the crew to systematically elicit information from them to inform the design of their displays and panels.

The cockpit is a dynamic and time-pressured environment, where information, events and pilots' tasks are interwoven and are in constant change. Gaining reliable design data from this environment requires a method that is non-intrusive to pilots thought processes and non-interruptive of plots' concentration and the cockpit information-work flow as a whole.

The data that needs to be acquired from the pilots to inform the design can be summarised into the following questions:

Q1 - What information do pilots obtain from the cockpit environment?
Q2 - How do pilots use this information?
Q3 - What do pilots do when the information they need is not available?
Q4 - What strategies do pilots use to acquire or retrieve non-apparent information?

The method required has to help us answer fundamental questions to all interface designers, *what*, *when* and *how* do pilots need information to complete their work successfully and in a timely manner.

This chapter starts by discussing how the selected information elicitation technique was tried out and modified to obtain information directly from pilots whilst taking into account the nature of the environment they are operating in. There is a need to obtain such information directly from pilots as early as possible in the design process to extract the full benefits, such as, (1) prevention of accidents, (2) ease of pilot training, and (3) design cost effectiveness.

There are several benefits to 'getting it right the first time': (1) it is more cost effective, rather than later detecting problems embedded in the interface at the interface testing phase, where changes to the interface become more costly. This is how it is currently practiced in the industry (Figure 3.1: Current interface design process e.g., Singer, 2002).

Another benefit is (2) prevention of incidents and accidents, needless to say, saves lives and avoids costly replacement of equipment. In several accidents the contributing factor was pilots' misunderstanding of the automated system or misinterpretation of what were the system's intentions (e.g., Aeronautica Civil of the Republic of Colombia, 1996). Lastly, (3) learning from the pilots directly and so later being able to support the strategies they use to manipulate data throughout the flight will also make it easier for pilots to understand during training (Lintern, 1995).

The search for an appropriate technique included several fields, such as Aviation Human Factors (e.g. Garland, Wise, & Hopkin, 1999; and Cognitive Engineering e.g. Sarter & Amalberti, 2000). The search was then further extended to include organizational development studies, were Participatory Research technique is used extensively to understand the underlying processes (Wadsworth, 1998). Aspects of these techniques were then fused to create a hybrid technique, the application of which is discussed in chapter five.

For over half a century, the Aviation Human Factors field had an amassing experience in designing for pilots and developed techniques for acquiring meticulous statistical measures of pilots' bodies in order to design ergonomic cockpit layouts. However, this experience, of designing for the pilot, does not appear to be transferred to the design of the information interfaces. For example, in the case of the design of cockpit interfaces pilots have only recently, as reported by two aircraft manufacturers (Newman & Greeley, 2001 - Lockheed; Singer, 2002 - Saab), started to be involved in design, during the testing and evaluation of interfaces. In this case the interfaces have already undergone lengthy development, likely without input from Human Factors specialists (see the center of Figure 3.1: Current Interface Design). At this late stage in design any changes suggested, as a result of pilots testing and evaluating interfaces, are not likely to be implemented due to changes being costly and time consuming.

Ergonomists study the body of the pilot before designing the physical set up of the cockpit, in order to support the limitations of the body and take advantage of its' shape and movements; similarly, there is a need to use Cognitive Engineers (Sarter & Amalberti, 2000); Wickens & Hollands, 2000)) to study cognition of pilots to support their abilities, limitations and make the most of their natural cognitive processes. There is a need to acquire a technique that will study pilots' cognition in their operating environment, and then suggest appropriate designs to support it.

So what is the environment that pilots operate in everyday? Pilots work in a time-critical, complex and dynamic environment, which depends on the outcomes and fusion of both, the external environment and technological factors. All these factors fuse in a continuous multilayered information stream that pilots and automation have to process.

The challenge here is to gain an insight on intricate details of the processes, both cognitive and operational, that pilots have to go through to operate in their working environment without interrupting or influencing them or the situation. The data collection technique used to support the design of future cockpit interfaces should also help acquire information to understand how to support these processes in a real world environment. This requires a technique that does not intrude on pilots' natural thought processes, but informs on what happens around pilots in the environment they operate, and also on what constitutes information processing that happens in pilots' minds.

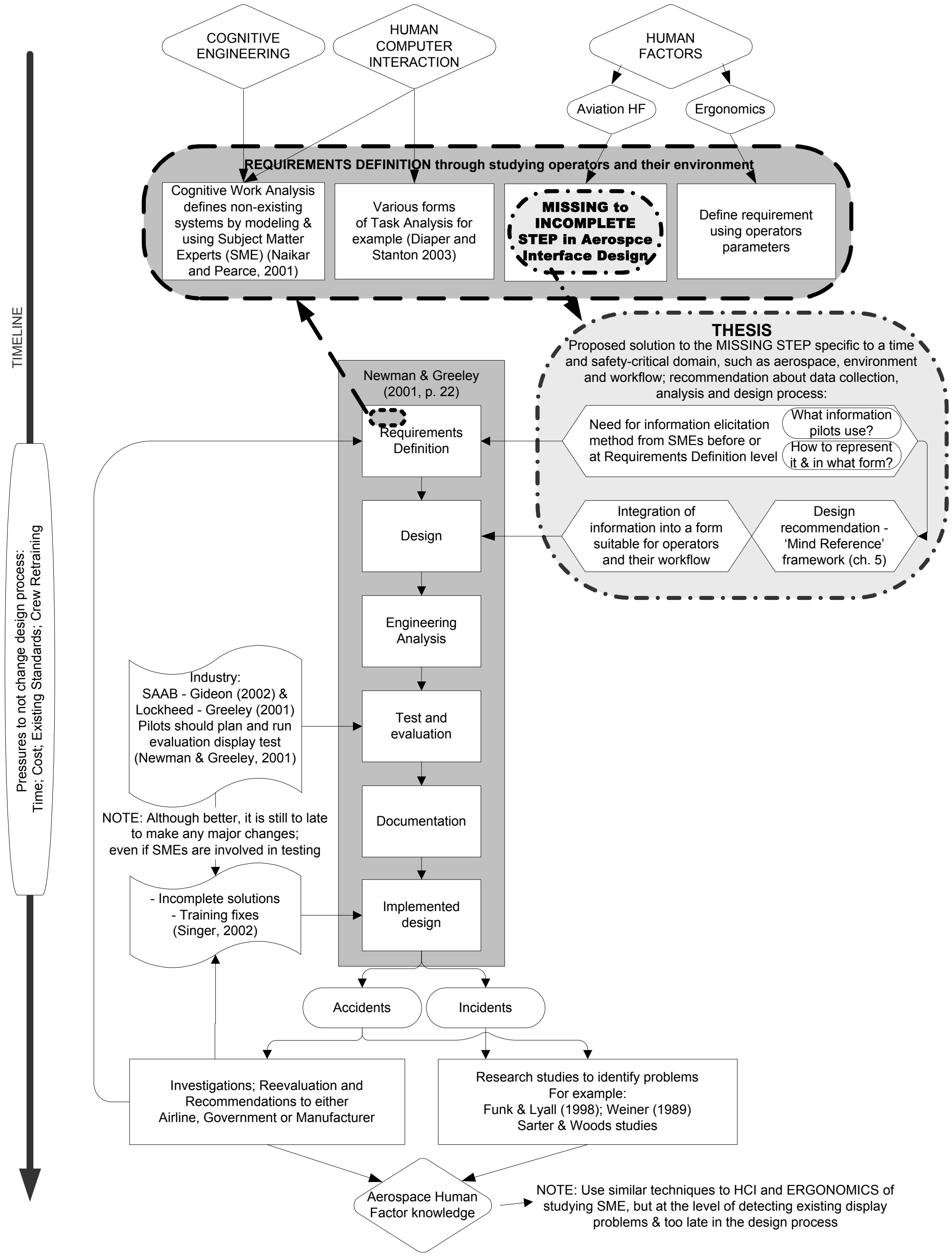


Figure 3.1: Current interface design process in aerospace

Many techniques used (Figure 3.2) by Human Computer Interaction specialists (Diaper & Stanton, 2003) to study people in their working environments are borrowed from psychologists, sociologists and ethnographers (Cooke, 1994). These techniques include observations of people performing activities whilst a third person video records the activity, and also include verbal protocols and various types interview techniques (Helander, Landauer, & Prabhu, 1997).

Video and audio recording the cockpit environment and pilots' behaviour during a flight leaves subjective interpretation of what has happened. *Self-reporting* (Buchman, 1984) and *interviewing* pilots with the right set of probing questions brings the researcher closer to understanding what happened during the flight. However, not every person is able to express or verbalize the processes that are happening while they perform their tasks. Moreover, pilots are experts at what they do, but they might take some information processing for granted, assuming that it is obvious to everyone. For example, it is a second nature for pilots to think ahead and have a contingency plan in case of an emergency, but it is not obvious from simple observation or it can be missed if the specific question about it is not asked during an interview.

Laboratory studies that are used successfully by Human Factors specialists to identify problems in some interfaces are often too narrow and too specific, due to restricting experimental conditions and an environment too far removed from the real operating environment. Laboratory studies can identify particular problems or tasks the pilots have difficulties with, but do not address underlying design problems, such as the absence of an application of a cockpit design rationale throughout the system. It can be argued that using conclusions gained from such studies may lead the researcher to lose an understanding how pilots deal with the uncertainty of the real operating environment. These studies are mostly specific to testing an experimental hypothesis and are not exploratory by nature. Laboratory studies cannot inform about where in the real environment pilots acquire the information they need if such sources are not provided on the test interface.

Through interpretation of observations, selective analysis of video and audio recorded data or by omitting the right question during the interview the valuable information may be eventually lost about the key cognitive processes that happen inside pilots' minds while operating in a real environment.

Additionally, *retrospective interviews* and *structured questionnaires* are common techniques that are used to inform design (Klein, 1989). However, the interview, for example, cannot capture the temporal aspects of the aerospace environment and pilots' time dependent activities. The questionnaire is restricted by the predetermined content of the questions, which cannot adapt to the answers of already answered questions by the pilot. These techniques, in most cases, look for confirmation of information that is already known to the researcher. These techniques are poor at discovering from real-time observations and pilots' own interpretations of the information they use, for example, the presentation form, frequency, quantity, quality and timing of information. These techniques alone disturb, or fail to trace, the inherent dynamics of pilots' work and the complex information flow that needs to be understood to inform interface design. In addition, these techniques can miss the implicit knowledge that pilots' use and rely on.

Methods of acquiring requirements in the real-world of the operator for design of the interface: The missing step in Aviation domain

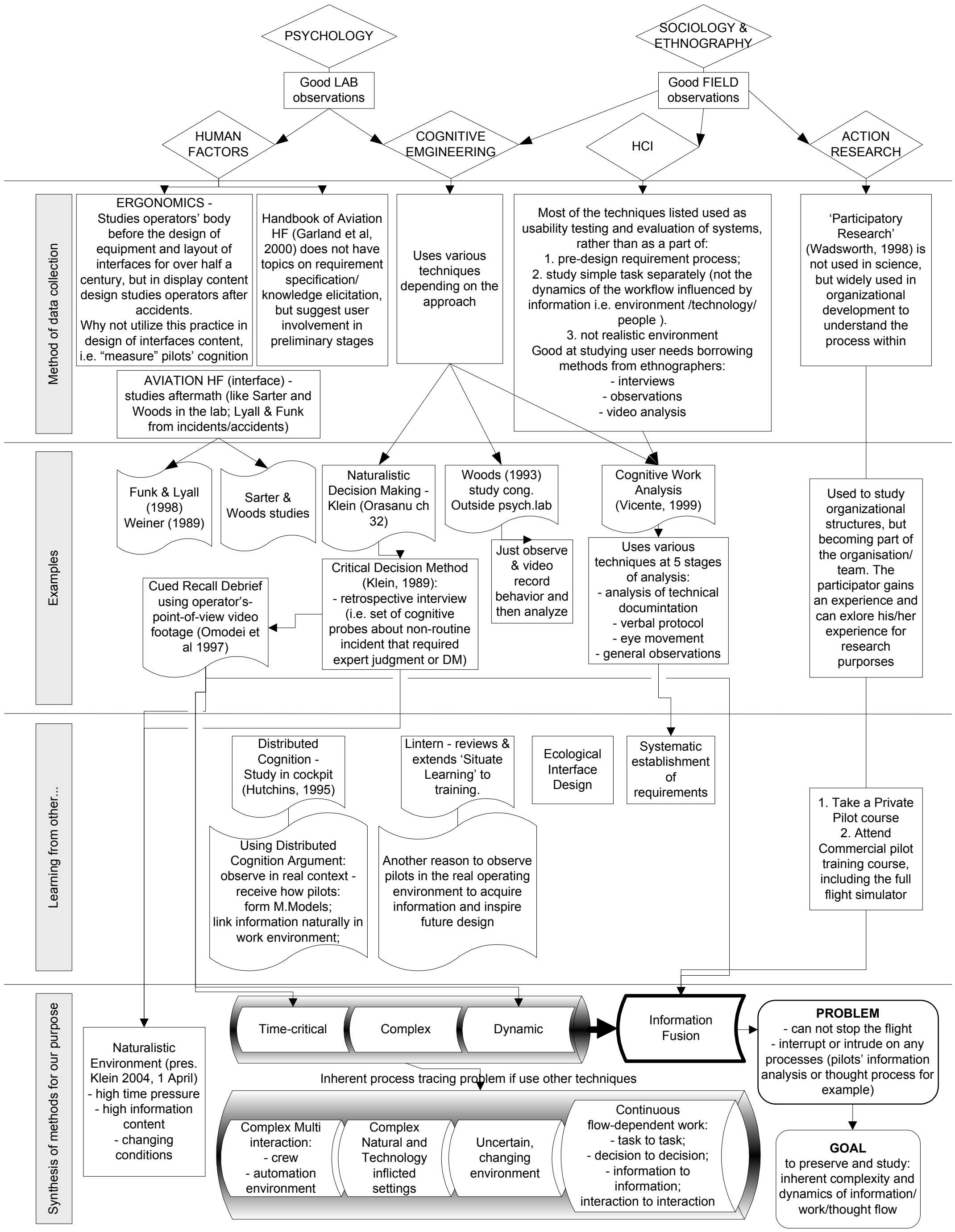


Figure 3.2: Methods for acquiring requirements

With these data collection issues in mind, the search is extended to cognitive engineering, where researchers have faced with similar problems. They too are learning about human decision making process in real world settings that cannot be easily replicated in the laboratory and are hard to observe in real life due to the hazardous environment that operators work in. Omodie, Wearing, McLennan and their team developed a 'cued-recall debrief method' to study the decision making processes of firefighters (Omodei, Wearing, & McLennan, 1997). They studied firefighters in their real-world setting. This technique relates to a Critical Decision Making method that studies operators' naturalistic decision making through a retrospective interview that uses a set of cognitive probes about a non-routine incident (Klein, Calderwood, & Macgregor, 1989). However, the cued-recall debrief method uses video and audio footage recorded from a head-mounted camera on the operator for cues for recollection of external and mental events that have happened during the recorded incident (Omodei *et al*, 1997).

Omodei, Wearing and McLennan (1998) developed a cued-recall debrief method to systematically investigate human decision making and the underlying cognitive processes in a real setting of a command and control environment. This consists of a two-stage replay-cued debriefing procedure. The first stage includes video and audio recording of the operators work from their head-mounted camera and then, as soon as possible, after recording, this video and audio footage is reviewed by the operator and the researcher. At this stage the operator takes the perspective of the 'insider' and relives what happened earlier as he/she watches the video and audio recording taken from his/her own-point-of-view. The operator's comments on the mental events, such as thoughts, choices, feelings, are recorded over the original tape. In the second stage the operator takes a perspective of the 'outsider' while viewing the video and audio footage with his/her own comments. Only at this second stage can the researcher ask probing questions in order to tap into the operator's fundamental cognitive processes.

Omodei *et al* argue that using head-mounted-camera footage for cued-recall-debrief produces valid and reliable reports on operator's own experience because (Omodei et al., 1997; Omodei, Wearing, & McLennan, 1998):

- The operator does not take it personally and cannot see themselves; i.e. not conscious of themselves when watching a replay.
- It represents the closest match between the initial and the replayed visual perspectives.
- Accuracy and comprehensiveness of recalled material is greatly enhanced being cued from their 'own-point-of-view' video and audio commentary
- It produces a powerful stimulus for evoking recollection based on review of cognitive theories (discussed next).
- It recalls a wide range of cognitive and affective experiences.

Omodei *et al* (1997), grounded their argument in cognitive theories, and reported that when operators view their own-point-of-view footage, it triggers:

Through…	**Recollection of …**
… perceptual cues synchronized in time and space	→ mental events associated with decisions
	→ essential temporal aspects of

		cognitive processes
… being cued by specific items, rather than cued by questions (Cantor *et al,* 1985)	→	retrieval of episodic memory that is organized by time, place and perceptual characteristics
… motion of the camera and activity of the operator (Neisser, 1976)	→	perceptual schemata rooted in locomotion & activity; recall of kinesthetic memories
… recall of non-verbal cues	→	motivation, memories and affects
	→	pre-verbal experiences, rather than a coherent & logical progression story that would be prompted by the researcher
	→	non-verbal holistic phenomena, and intuitive decisions at the time
… replay and pause	→	inchoate experience that can be put into words

These recollections specifically triggered by cues from images taken from operators' own-point-of-view can reveal not only the source of decisions that operators made but, more importantly for this research, these images can trigger the recollection of *how* the operator obtained the information to make those decisions. Through perceptually synchronized cues in time and space, the operator is able to recall, not only current methods of collection of information, but also remember what previous experience the operator based these on. It allows retrieval of information sought at the time of each action and the thought at the time of each reaction.

Using this cued-recall-debrief as the main elicitation technique for the definition of requirements for this research gives an advantage over commonly used techniques, like various types of interviews, questionnaires, task and documentation analysis, ethnographic studies and types of participatory design methods that involve users in the design process in Aviation Human Factors (Garland et al., 1999) and Human Computer Interaction (Helander et al., 1997) communities. Advantages of this acquisition method are:

- Acquires information directly from the operating environment.
- Places more realistic demands on the operators.
- Provides cues that are pre-verbal, 'holistic-intuitive' (Kuhl, 1985), and temporal.
- Gives probing cues, like motion, non-verbal cues, and some that operators detect and are undetectable to the researcher.
- Involves the operator in a way that is directly informative to designers in understanding what are the needs of the operator.
- Taps into operators' implicit knowledge.
- Traces evolution of information during workflow

Using the cued-recall-debrief method *temporal and spatial properties of the operating environment* and *temporal and spatial aspect of pilots' cognitive processes* can be retrieved. These are of most interest for the purpose of this research, when designing to support pilots' work in a time-critical operating domain. This method allows for continuous, non-intrusive, non-reactive, real-time documenting of the events with minimal distortion of the complexity and dynamics of the operating environment, because it is less likely to intrude or distort the pilot's experience, being attached to pilot's head and so not visible to the pilot (i.e. 'out of sight, out of mind') (Omodei et al., 1997).

This method is the new generation of verbal and retrospective protocol. It allows both recording of current actions, such as verbal protocol, and it allows documenting intentions of the operator using one method.

This method will allows the researcher to understand how to better support the *spatio-temporal aspects of cognitive processes* that pilots go through while they are searching and sorting and consolidating information. It allows pilots to recollect pre-verbal experiences and put these inchoate experiences into words through replay and pause of the reviewed video and audio footage. It gives a unique opportunity to suspend time without interrupting real-time events or influencing the outcome of the pilot's action and gives an insight into pilot's information processing.

At this point it is appropriate to highlight the disadvantages of this method: (1) it requires the use of expensive equipment, such as a flight simulator; (2) it requires real operators, which can be difficult to schedule and generally few are available to participate in the study; (3) it requires lengthy transcription of video and audio data where an extensive analysis has to be preformed. However, it is argued here the results acquired do outweigh the disadvantages, as shown in latter chapters of this thesis.

3.2 Preliminary Study

A preliminary study was performed to test whether a cued-recall-debrief method was an appropriate information elicitation technique. This study was then used to prepare for a further empirical study: (1) to establish the suitability of the method, it was tested and refined for the use in further an empirical study; (2) to determine the form of the analysis appropriate for the data collected; (3) to test the procedure set out for further a study, and in parallel; (4) to test the operation of equipment before taking in it into the field.

3.3 Method: cue-recall-debrief

The methodology proposed is a modified cued-recall-debrief method based on the operator's own-point-of-view footage, a method that was previously used by Omodei *et al* to study decision-making strategies (Omodei *et al*., 1997). This method was extended to inform the design process. The probing questions were formulated for the purpose of this study and the future empirical study to extract information directly from the pilot to support the design of future cockpit interfaces.

The preliminary study was conducted at Swinburne Computer Human Interaction Laboratory (SCHIL) at Swinburne University, in December 2000 to prepare for an empirical study of pilots to be run the following year at the Royal Australian Air Force base in Richmond, Australia.

3.3.1 Material and the Experimental Scenario

In the preliminary study a commercial-of-the-shelf, the Microsoft Flight Simulator 2000, software was used to simulate a flight from the beginning to the end.

The scenario was a complete short flight, from engine power-up to power-down. The choice of the scenario was determined by the following:

- To support pilots' entire work throughout the flight the scenario had to last from power-up to power-down.
- To capture the richness, completeness, and dependency of information between tasks as well as the continuity of pilots' work- and information-flow the scenario had to be uninterrupted from power-up to power-down.

3.3.2 Participant

The only participant in this study was male in his early thirties. He was an experienced computer game player with previous flying experience. The participant will be interchangeably referred to as a participant and as a 'pilot' throughout this chapter.

3.3.3 Equipment

A colour lightweight lipstick camera was used. It was attached to an elastic band that was adjusted to fit participant's head. The head-mounted camera was adjusted to be on the left side of the head at the participant's eye-level. Once worn it was adjusted to point in the direction where the participant was looking and the focus was adjusted.

All audio produced by Flight Simulator 2000 and the participant's utterances were recorded through several microphones positioned in the room.

3.3.4 Task and Procedure

Prior to the study the participant was asked to complete an inform and consent form that laid out the participant's right to withdraw at any time, there was also a brief about the study and the ethics committee contact details in case the participant had a need to discuss the way the study was administered.

The participant was to fly a short flight, which was recorded on a videotape. The videotape captured what the participant saw from his head-mounted camera during the whole flight and recorded the sound produced by the software, simulating sounds, such as flaps retracting, engine noise (i.e. accelerating and decelerating), wheels touching down on the runway and brakes being applied.

After this flight the participant was invited into a debrief room, where equipment was set up to replay the flight as the participant saw it, and then record the comments of the participant on a separate debrief videotape, which captured the original footage together with his debrief comments.

The debrief consisted of two parts: 1st Free-flow Debrief and 2nd Debrief with specific questions. In the first part, called Free-flow Debrief, the participant was asked to answer the questions listed below, which were read to him before he watched a replay of the recorded flight and gave comments based on those questions. The participant was not interrupted during the whole recollection, in order to observe and document the natural flow of information that he experienced while flying the aircraft. However, the participant was told that he could pause the tape at any time if he wanted to explore any particular point of the flight.

1st Free-flow Debrief questions:

- Walk me through the flight; tell me…
- What have you experienced?
- What have you done during the flight?
- What were you thinking about?
- For you what were the important points of the whole flight from power up to power down?
- Why were these points important for you?

While the participant viewed a replay of video and audio footage taken from the head-mounted camera, he spoke about his recollection of events that were recorded onto a separate debrief videotape together with the original video and audio footage. This was done to keep the footage and audio recording of recollection synchronized with the action captured by the original video and audio footage.

The second part of the debrief was modified to inform the design process about the pilot's use of and need for information at any point throughout the flight. The participant was asked the series of questions below:

2nd Debrief with specific questions:

> Researcher: "During this debrief I will be putting the videotape on pause and asking you a set of questions listed below."

(Present oriented questions)

- What was going on at this point?
- What were you thinking about at this point?
- What were you doing at this point?
- What were you using to achieve that?
- What was the aircraft doing at this point?
- What were you doing with the aircraft at this point?
- What were you looking for at this point?
- What did you need to consider at this point if anything?
- What are the constraints upon your actions at this point?

(Future oriented questions)

- What is going to happen next?
- What would you do next? … with the aircraft?
- What do you need to do to achieve that?
- What will the aircraft do in the next couple of moments?
- What would you do with the aircraft next?
- What kinds of information will you want/need to have available in the next couple of moments?
- What do you need to consider next?
- What will be constrains upon your action next?

In addition to the *present* oriented questions that were needed to clarify what information processing was happening at any moment throughout the flight, it was necessary to uncover if the pilot was considering any information that would effect the future of the flight, also at any point of the flight. The decision to ask *future* oriented questions was also influenced by the first flying lesson the researcher had with her instructor. The instructor said, "… you as a pilot should always be ahead of the aircraft in the manoeuvre that you will be performing. As soon as the aircraft is ahead of you, you loose control of the aircraft." This was the inspiration to set up the questions about pilots' future intentions and see how to support such important activity through the flight.

The questions, both future and present oriented, were asked at an interval of one minute throughout the whole flight, while the researcher paused the original videotape and the second debrief tape captured both, the timing where the original videotape was paused and the comments of the participant. This helped to determine what the participant was doing, thinking and what information was being used at a given time of the flight. Consecutive one-minute intervals during a debrief were used to continuously trace the information flow used by the pilot throughout the whole flight. As the second part of debrief progressed, the questions were adjusted to be asked around specific events, such as flight stages, which were determined from the first part of debrief. It was found that the information and considerations at one-minute intervals did not change as much as they did around the event points. The questions were subsequently changed to be asked one-minute before and after the event, rather than using the initial exploration of asking questions around consecutive one-minute intervals. For example, events like the beginning and the end of climb and turns appeared to be crucial points where the participant assessed the situation, using available information, and made decisions that affected the rest of the flight.

3.4 Analysis of real time data

The analysis strategy adapted here evolved in such a way as not to alter the properties of the pilot's operating environment. The analysis aimed to help identify the information that the pilot required at any point of the flight and to help answer questions that were to inform the interface design process, including:

- What information do pilots need to perform their work-flow, i.e. a series of information-dependent tasks?
- What do pilots do when the information is not available?
- Where do they gain information when it is not available?

- *Do* they obtain this from the surrounding environment?
- If not, how do they then acquire information?
- How do they retrieve it?
- How do they use this information?

To start the analysis, all videotapes were transcribed. The first tape transcribed that was the original audio and video footage from participant's head-camera together with his first uninterrupted comments of events (i.e., 1st debrief). The second tape had the original video and audio footage synchronised with the answers to specific questions initially asked by the researcher at one-minute intervals, which later changed to being asked around the flight stages and events (i.e., 2nd debrief).

The analysis of the information from the first debrief tape evolved through several iteration of tables. While transcribing the audio recording of the participant's comments, a pattern of work-flow started to emerged. The pattern consisted of a recurrence of four categories of what the participant did: *attended to* something, *act upon* something, *thought about* something or *planned for* the next event. Based on these categories a table was devised that consisted of four columns: *attended to*, *act upon*, *thought about* or *planned for* (see a fragment of the Table 3.1 below and the full table in Appendix 1, Table 3.1).

<table>
<tr><th>A</th><th>B</th><th>C</th><th>D</th><th>E</th><th>F</th></tr>
<tr><td rowspan="11">Timeline</td><td></td><td>Attended to</td><td>Act upon</td><td>Thought about</td><td>Planned for</td></tr>
<tr><td>1.</td><td>I'm taking a note of what time it was on the clock</td><td></td><td></td><td></td></tr>
<tr><td>2.</td><td></td><td>trying to keep my southerly heading</td><td></td><td></td></tr>
<tr><td>3.</td><td>watching the clock</td><td></td><td></td><td></td></tr>
<tr><td>4.</td><td>looking for some indication on the ground of a building</td><td></td><td>an indication of how far south I am</td><td>So I know what altitude I'm going to be at for my return flight to land</td></tr>
<tr><td>5.</td><td></td><td></td><td>I've realized…</td><td></td></tr>
<tr><td>6.</td><td></td><td>I'm still climbing</td><td>because I haven't actually got the trim set properly</td><td></td></tr>
<tr><td>7.</td><td></td><td></td><td>So I decided not to bother with changing it (trim)</td><td></td></tr>
<tr><td>8.</td><td></td><td>put the nose down just a bit</td><td></td><td>Need to loose that extra altitude</td></tr>
<tr><td>9.</td><td>I see the top of the building just appeared</td><td></td><td></td><td></td></tr>
<tr><td>10.</td><td></td><td></td><td>I'm starting to think how far South I am</td><td></td></tr>
</table>

	11.			I've been travelling down South faster then I normally do	

Table 3.1: A fragment of the table 'Based on 1st Debrief Transcript'

The order of the columns captures the work-flow (i.e. participant *attended to*, *act upon*, *thought about* or *planned for* and again *attended to*, *act upon* etc.), which are based on the participant's first debrief comments. The first column indicates where, or to what, the participant *attended to*, for example, the participant looked at the clock (see cell 1C in Table 3.1). The items in this column were related to a specific piece of information or were related to an action that he needed to do next, for example, the participant wanted to keep a southerly heading for a minute (see cell 2D in Table 3.1). Hence, the next column listed was called *act upon* and listed the instances where the pilot 'acted upon'. The following column listed *thoughts about* the effects of his action, for example, the participant thought about looking for a landmark that would tell him how far south he is (see 4E in Table 3.1). The last in a row, but not in the work-flow, is a *planned for* column, where the participant planned the next manoeuvre (see cell F8 in Table 3.1). The end of each row (see column F in Table 3.1) links to the first column (see column C in Table 3.1) of the following row. This is repeated until the end of the flight comments.

The layout of participant's comments in Table 3.1 established that columns, *thought about* and *planned for*, were associated with the next manoeuvre of the aircraft. It was noticed that the participant collected and processed most of information around the aircraft manoeuvres. These were points in flight, where one flight stage changed into the next flight stage. Following this finding, Table 3.1 was revised and Table 3.2 transpired as a result, where columns were flight stages and rows documented the comments the participants made regarding the information he was using during that stage (Table 3.2 fragment below and the full Table 3.2 in Appendix 1).

Table 3.2 shows the flow of participant's thoughts at each flight stages throughout the flight. It provides an indication of the kind of information and cues the pilot uses at each stage of the flight

	Flight stages			
	Initial Climb	**Climbing Turn**	**Intermediate Climb**	**Climbing Turn to level out**
Timeline	Concentrating on altimeter	Approaching 2000	Focus on climb angle	Turning
	Keeping direction	Turn right (East) & climb to 3000	Focus on altimeter	Focus on the clock
	Keeping airplane stable	Conducting steady turn	Going East	Climbing & banking
	Rudder movements for North direction	Make adjustment in climb & turn	Focus on compass	Concentrating on compass
	Check airspeed between 60 & 80	Focus on compass	"Check the clock on the next turn at 3000 to travel 3 minutes."	Get barring South
	Focus on altimeter	Line up East	Look at clock	Use joystick & rudder to turn

	Look outside	Minor adjustments to on East heading		Keep an eye on the speed

Table 3.2: A fragment of the table 'Analysis of Stages of flight of the 1st Debrief Transcription'

The *first part of the debrief* was informative about the flow of events, but lacked specific detail about the information processing that the pilot did during the flight. The *second part of the debrief* provided specific detail and gave preliminary insight into possible information structures that the pilot used during the entire flight.

During the second part of the debrief the participant was asked two series of questions related to his thoughts and actions about the present and the future, which were asked initially at one-minute intervals. However, as the second part of debrief proceeded the questions were timed to be asked around the events, rather that at one-minute intervals, because this was found to be where most of the information was processed by the pilot. It was found that the information flow and the pilot's considerations did not change much at one-minute intervals but did change considerably around the flight stages.

After transcribing the second debrief, there was an obvious separation of information into information about the present and the future events, because of the present and future oriented questions asked during the second debrief. This strategy of asking questions at a particular time interval had generated two specific types of information: (1) the temporal orientation that determined the timing of events throughout the whole flight; (2) present and future oriented information that determined the information need at any point of the flight.

The analysis showed the continuity of information throughout the flight, showing that the pilot was constantly seeking out information in order to be in control and ahead of the aircraft at all times. The full outcome of the debrief analyses is represented in a timeline-diagram (Table 3.3, Appendix 1). As this was a preliminary study and was aimed to test and further develop a cued-recall debrief method to suit the needs of this thesis, the results of this study are not discussed in detail, but are provided in the table 3.3 and when appropriate discussed throughout the thesis.

The results in (Table 3.3 Appendix 1) trace the temporal aspects and the information flow, based on the activity of the pilot and the timing of events. The table shows what information and cues the pilots was processing when achieving present and future tasks, or preparing for present or future events.

Based on the timeline-diagram, a sample of an interface was prototyped (Appendix 1 Figure 3.1). It was put together to assess whether the information elicited during the preliminary study was sufficient and helpful in composing an information interface.

3.5 Outcomes: modified cued-recall-debrief method

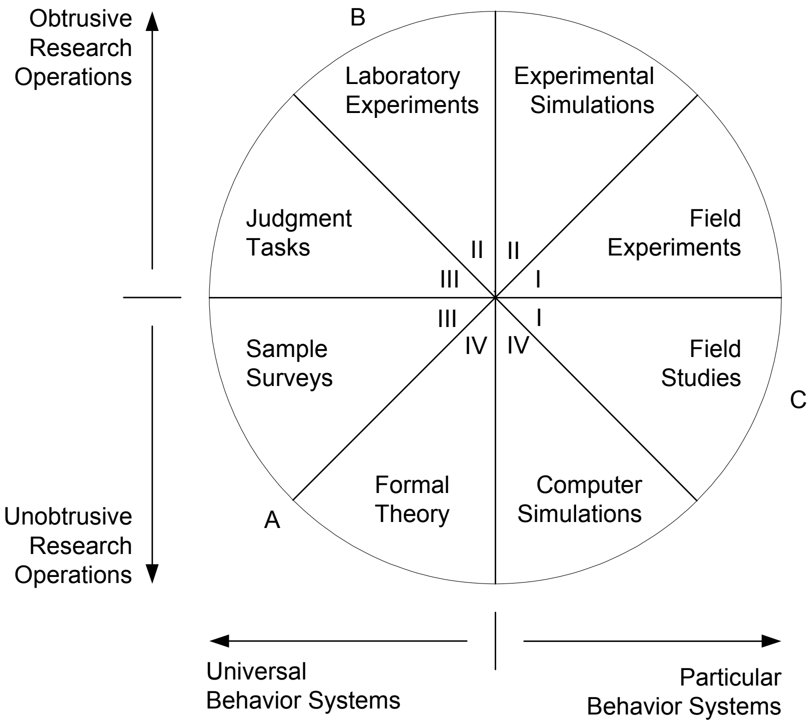
The finding suggest that the proposed cued-recall debrief method does not interrupt pilot's work-flow and preserves the continuous flow of information throughout the flight. It showed how tasks and information interweave and are dependent on each other. The series of questions oriented to present and the future, asked during the second part of debrief, helped to continuously trace the information flow and its evolution from one point during the flight to another.

Based on the above information, stages of flight were constructed as the pilot recollected them, capturing how the pilot viewed the whole flight. Table 3.3 (Appendix 1) captures all the analysis of data into one table across a time continuum. The layout of information in the table 3.3 (Appendix 1) shows the information and cues that the pilot relies on when working on either performing current tasks or planning for the future tasks. The elicited information on the timeline-diagram traces the information needed by the pilot throughout the flight.

The *two-stage debrief process* helped to modify the questions to be used in a future empirical study. It helped to identify questions that prompted repetitious responses in both debriefs. These questions were subsequently combined and the *two-stage debrief* was modified to *a one-stage debrief.* The one-stage debrief allows for more efficient information retrieval and retains the content of the questions as in the two-stage debrief, plus additional questions were used to cue the pilot in order to inform an interface design. This shortened the debrief time considerably, but is not likely to effect the quality of information being acquired, as the same information and in more detail was available in the second part of the debrief.

3.6 Validation of the insight obtained from the Cue-Recall-Debrief method

To consider validation of a research method, the method should be classified where the weaknesses and advantages are taken into account in comparison to other methods. Runkel and McGrath break down types of scientific research onto two axes (Figure 3.3), the first axis is related to the level of researcher obtrusion; the second axis relates to the level of universality of the behaviour of the studied system. Dividing research types upon these axes, they highlighted three concerns: the 'generality of actors' (i.e., how representative is the sample population), the precision of measurement of behaviour and the effect of context on research results. The balance, or at least a compromise between highlighted concerns, needs to be recognised in analysis and validation of results of any research.



I. Settings in natural systems.
II. Contrived and created settings.
III. Behavior not setting dependant.
IV. No observation of behavior required.

A. Point of maximum concern with generality over actors.
B. Point of maximum concern with precision of measurement of behavior.
C. Point of maximum concern with system character of context.

Figure 3.3: Research Strategies from Runkel and McGrath, 1972.

This thesis fuses multiple methods to balance the three concerns. The concern over generality of actors is addressed in each of the methods used. All research participants were pilots with similar experience and were balanced for every instance of the research. The results of the studies are not being generalised to other actors. The precision of measurement of behaviour is controlled and measured in the experimental evaluation of the designed display features described in chapter 8. Lastly, understanding the effect of context and consideration of its effect on research results are discussed in the observation and participation in the pilot's training program (Chapter 4) and the empirical study (Chapter 5).

Studying pilots information processing out of context has a detrimental effect on research results, as can be seen later in this thesis; the context actually determines how pilots understand the information. The pilots' safety critical and time-dependent context and the phase of flight dependency of information are important parameters of how information is selected and processed by pilots. The professional pressure of being a pilot that can deal with any unexpected event in a competitive environment also needs to be considered. For the empirical study a modified Cued-Recall Debrief method has been chosen as it has minimal influence on pilots' operating environment.

The validity of Cued-Recall Debrief method can be criticised if these were the only results contributing to the outcomes of this thesis. The method uses the real-world setting (i.e., highly contextual) and to the greater extent does not intrude on the participant's behaviour. The Cued-Recall Debrief has an advantage over other direct observational methods (Rubin, 1994), such as think aloud, where the participant has to think (i.e., given extra time to think over his/her action) and verbalise his/her behaviour, as these extra processes influence the sequence of actions when performing the task. In Cued-Recall-Debrief the participant is left to perform his/her task in the real-world setting without any influence from the researcher and only after the event is asked to comment on the past events.

The Cued-Recall Debrief in comparison to other retrospective methods suffers to the same extent from subjectivity of interpretations of events and actions that happened. However, the findings in this research strongly indicated similar pilot responses, and so consequently similar interpretations, when comparing four pilots and their experience in two types of flight, automated and non-automated. The results showed a consistent result across all participants with reference to the type of information and how all participants used that information.

Cued-Recall Debrief produces reliable reports, as revealed by Omodei, Wearing and McLennan (1997; 1998), in comparison to other type of recollection methods using video recorded data, which are interpreted by the participant or a researcher. In a Cued-Recall Debrief the participants are able to immerse into events from his/her point of view through a multitude of triggers and cues discussed earlier, which are not available from other angle of recoding, where the participant is seeing himself or herself performing the action and conscious of themselves.

3.7 Conclusion

This preliminary study was conducted to:

1. Test the suitability and refine the *information elicitation technique* that will be used in further empirical studies.
2. Assess the suitability of data collected and determine the form of analysis.
3. Test the *procedure* set out for the empirical study.
4. Test the operation of *equipment* before taking in it into the field (i.e. full flight simulator)

The preliminary study goals were successfully fulfilled. The selected *information elicitation technique* was found to be suitable. It helped to collect data from the pilot in an environment close to the 'real-world' environment with minimal, to no, external interruption of the operating environment and the pilot's work-flow. The questions developed for preliminary study have been tested and modified to eliminate repetition in pilots' answers and to reduce the data collection and analysis time, but not to compromise on the quality and quantity of information acquired.

The data produced as a result was found to be helpful in beginning an understanding the information demands of the pilot.

Lastly, the equipment used worked well, apart for initial set up problems, which were dealt with successfully. If these problems were to arise in the field they could be easily fixed. The most important and most difficult problem to rectify immediately is the low power battery for the lipstick camera, which has to work for the duration of the flight without interruption. To overcome this problem additional batteries were acquired. This flexibility allowed at least one battery charging and one ready to supply additional power to the camera if required.

Apart from the above, there are other helpful outcomes in this preliminary study that are referred to later in the thesis. For example, in general the stages of the observed flight appear to match conventional stages of flight in commercial and military operations. It was subsequently found that commercial and military pilots broke down their flights into similar but larger chunks when talking about, or briefing for, a flight among themselves. Another similarity between the finding in this study and further findings in this thesis is that the information layout in the timeline-diagram (Table 3 Appendix 1) is similar to how pilots view the whole flight along a time-continuum. The pilots later observed, similar to the participant in this study, shift their thoughts back and forth along this timeline of the flight in order to assemble the required information to be prepared for forthcoming events. This finding also supports the researchers flying instructors basic rule 'the pilot has to think ahead and have a contingency plan in case of an emergency'. This is taught during the early stages of training to every pilot.

Overall, the study was an informative and a useful learning process helpful about the problems that are likely to be faced in the empirical study. It gave a glimpse at the kind of information the proposed modified method will elicit. The data acquired from this preliminary study is appropriate for the purpose of the thesis and produces sufficient information to inform the interface design process.

Chapter 4: Understanding 'Pilot Experience'

This chapter is written in the first person, 'I am', because it is necessary to bring to the researcher's personal experience of acquiring knowledge about what it takes to become, and be, a pilot and to operate an automated 'beast' which the modern aircraft has become.

This chapter explains why and how I had to prepare for an empirical study:

1. I learned about what steps pilots take to become pilots, by observing pilots during line operation of commercial airlines, which aided me in acquiring terminology, commonly used abbreviations and professional jargon.
2. I outlined the difficulties the pilots face when they are transitioning from a non-automated to an automated cockpit.
3. I outlined strategies pilots use in dealing with automated cockpits.
4. I classified the problems in the current automated cockpit interfaces.
5. I discuss why there are problems in the automated cockpit.
6. I discuss what questions should be answered as part of the next step to overcome these problems.

4.1 Systematically acquiring an understanding of pilot experience

I wanted to have an opportunity to learn basic flying skills and learn about the fundamentals of flying that are ingrained in every pilot's mind. All pilots begin their training in the same way for all fixed wing aircrafts. I took lessons to become a pilot, the same way that most professionals begin their career in aviation. I logged over 60 flying hours on two different continents. This enabled me to encounter how my conceptions about flying an aircraft were formed.

Next, to gain experience of the conceptions pilots form about the operation of an automated cockpit and how basic flying knowledge is challenged by an automated aircraft, I attend a training course for an automated aircraft. With kind permission from Ansett Airlines in Melbourne Australia, I was able to participate in, and observe two pilots in a conversion course. The pilots took this course when converting from a non- or semi-automated aircraft to an automated aircraft, Airbus 320. I also was able to observe some of the difficulties that experienced airline pilots face when learning the operation of a new type of cockpit.

I also took a Computer Based Course on a Boeing 777, which is software that takes a pilot from a total overview of the aircraft to a detail description of each system, and selected scenarios of aircraft operation for each stage of flight, as well as emergency situations. This helped me to extend my understanding of modern aircraft across several types of aircraft from different manufacturers. It also provided me with a basic understanding from which I could compare the design of interfaces, and contrast the problems on two different types of automated commercial aircrafts.

Finally, I needed to learn about the aircraft that I would be conducting my empirical study on, an automated military cargo aircraft, C-130J-30 Hercules. I undertook a month of a Computer Based Course on a Hercules (similar to a Boeing 777 program), including having access to Training and Operational Manuals at a Royal Australian Air Force (RAAF) base, Richmond, Australia[1]. This course also allowed me to learn more of the specific terminology related to this aircraft type, to familiarise myself with the cockpit and layout of all the displays and instruments, and to learn the basic operational procedures. The training on the Hercules also added understanding of another cockpit type designed by Lockheed Martin, a military type, in addition to the two automated commercial, Airbus 320 and Boeing 777, aircraft.

To frame the empirical study, I intended to learn about how pilots search, use and manipulate the information presented to them and to identify how they overcome any shortcomings of current designs in everyday operations. During all three training periods, I had firsthand experience of flying all three aircraft flight simulators and a sit-in on scheduled flights on Ansett and Emirates Airlines. I also had access to Computer Based Training and manuals. All these experiences framed the research and gave me a broader view on the types of problems and challenges pilots face when flying and converting to a modern automated aircraft.

All of the above knowledge I discuss in this chapter is fundamental to the thesis and when considering the design of a modern cockpit, as concluded at the end of the thesis. This is because the advancement of current technology has created a gap in knowledge between the pilot, operating an extremely powerful machine that at times may appear to have 'a mind of it's own', and the engineer who creates displays, instruments and panels that have a huge scope of options through which an aircraft can be flown. This gap between the two professions is vast. This chapter identifies the problems pilots face and their roots. The thesis itself is an attempt to bridge this gap through an understanding of pilots' needs to operate an automated aircraft, as well as communicating this to an engineer in a suitable form, such as design guidelines and principles.

4.2 Learning and understanding pilot experience: step-by-step

4.2.1 Basic flying tasks, skills and knowledge

The intention behind attending Private Pilot Licence lessons was twofold. One, it is the first step towards a professional pilot career and all pilots follow this route. Two, it enabled me to follow through the knowledge steps that pilots take.

During my first lesson on the ground I learned what makes the aircraft go up and down, the elevators; what makes the aircraft turn left and right, the ailerons; how to increase and decrease an aircraft's speed in climb, cruise and descent, the combination of the above, and the use of the throttle to add the power required. The aircraft speed can be manipulated by pointing the aircraft nose up to decrease the speed of the aircraft, or by pointing the nose of the aircraft down to increase the speed and let gravity do the work. I learned that the aircraft is steered differently in the air and on the ground. Armed with just this basic knowledge I had my first flight, where I tried basic turns, climb, descent and even had my first landing. The most remarkable part of the whole experience was how easy and how it appeared natural to pick up the basic flying skills.

[1] Mark Thoresen and David Martin of the RAAF facilitated the research conducted in Australia.

Little did I know a that time that most of the work during my first flight was done by my instructor, such as trimming an aircraft to fly straight and level, so I did not have to struggle with the control column by pulling hard on it to climb, or by pushing it too hard to descend. The instructor adjusted, i.e. trimmed, the elevators by feeling the decrease or increase of pressure on the control column to make the aircraft fly the trajectory he wanted. Thus flying can be done with minimum effort. My instructor had monitored the fuel, any warning signs on the engine instrument panel, while also looking out for any air traffic outside. He was constantly assessing where we were in relation to other aircraft and the permitted three-dimensional training flying airspace. The instructor had to perform the entire list of safety checklists at each phase of flight, before start, before take-off, on the runway line up, after take off, after level off, before manoeuvres, before and during the approach, after touch down, and before and after the engine shut down. Apart from all the work the instructor-pilot was already doing, he had to communicate with Air Traffic Control and receive clearance for almost every phase of flight.

During several months of training I learned in detail what each of these tasks entailed and how to combine all the tasks the pilot had to perform to fly an aircraft efficiently. The work of a pilot does not begin at take-off and does not end after landing. The flight starts with planning the flight, informing the appropriate authorities about the intended flight, briefing the crew and passengers, pre-flying the aircraft, going through all the checklists before, during and right after the engine is started. In addition to flying the aircraft and performing regular checklists, the pilot has to complete special checklists such as, for special manoeuvres, or for executing an emergency landing. After landing the pilot has to check the aircraft, debrief the flight with crewmembers. The pilot needs to report that the flight was successful and the aircraft is on the ground to appropriate authorities, otherwise the search and rescue team will be dispatched to search for the crew and the aircraft that did not report back.

Planning the flight is the first step in any flight. Sometimes it can take the same amount of time as flying the aircraft. Before each flight the pilot has to plan and draw a route he/she will be flying. To calculate the route the pilot has to take into account, where and in which hemisphere he/she will fly, to allow for global magnetic variations that will affect the instruments in the aircraft. The pilot has to consider the time of arrival and departure, because having daylight could be essential to navigate to a final destination. The weather and terrain, local, en route, and at the destination have to be considered when planning the flight too. The pilot has to account for prevalent winds that might affect the course of the aircraft.

Finally, during planning, the weight and balance of the aircraft has to be considered for an entire flight. This will vary for each flight, because the number of passengers, their weight and luggage will vary, as may the fuel required, for example, due to adverse or favourable winds that could affect flight. This is compounded by the need for further compensation for the locations of passengers, luggage and fuel, otherwise it could unbalance the aircraft and make it impossible to fly and land.

Thinking and planning for a worse case scenario is also a part of the planning. This is when the pilot considers a possible diversion to an alternative airport, or returning to a departure airport due to bad weather or a malfunction. The pilot has to find a suitable airport or landing strip. Not all airports are suitable for all types of aircrafts, the length, the width, the quality of the runway are only a few considerations among others, such as, whether there is an Air Traffic Control controlling the airport space, the runway which may be used, the radio frequency it is at, and whether it will be possible to obtain permission to land. The fuel has to be recalculated again for an alternative airport, plus additional fuel for possible air traffic or weather delays.

When the planning is finalised and the appropriate authorities are informed, any crew and passengers are briefed, and the pre-flight of the aircraft begins. At this stage, the pilot must physically check the aircraft outside for signs of possible cracks or abnormalities. This check will also include oils and fuel checks in all tanks. The checks continue inside the aircraft by using standard checklists enforced by the aircraft manufacturer and the company that owns the aircraft. Most of the checklists are read from printed cards, to avoid mistakes and omissions.

Fundamental rules

The pilot still has not started an engine, but already a large amount of information and work has been undertaken. Once the engine is started, the work of the pilot is dictated by the 'rhythm' of the flight and not by his/her own pace, in contrast to the pre-flight stage. To be successful in being in 'tune' with the flight time, the instructor told me a fundamental rule, '*a pilot should be always be ahead of the aircraft in every action, manoeuvre and always have a contingency plan.'* If a pilot does not follow this rule, then he/she will have no control of the aircraft, instead the aircraft will have control over the pilot.

Aircraft are forgiving to pilots' mistakes. Even without an autopilot, they are designed and built to fly straight and level if they are well trimmed and balanced by the pilot. However, it is crucial for the pilot to always have in mind the next step (i.e., action in this case) and a contingency plan in mind. This enables the pilot to stay ahead of the aircraft, in case disaster strikes. Planning gives a pilot the advantage of not being taken by surprise and so having free mental capacity to execute an emergency plan, rather then having to catch up with what has just happened and then thinking of what to do about it.

A further fundamental rule of flying embedded in every pilots' mind is, *'Aviate, navigate, communicate. In that order*.' Once the aircraft is of the ground and safely in the air, the most important task of a pilot is to keep it that way. The next major task is to navigate the aircraft along the pre-planned route. When the aircraft is flying the flight plan, then he/she needs to communicate with Air Traffic Control. In an emergency the pilot will follow the same rule, first he/she would fly the aircraft, then navigate it to a safe landing, and only then transmit an emergency call.

Equipped with these fundamental rules, and with the flight plan, the pilot takes off and competition with time begins. The pilot has to be very efficient to keep up with the flight plan and to be 'ahead' of the aircraft. The pilot needs to retain information in memory about the flight, using short-term memory when given clearances and local information by Air Traffic Control (i.e., local air pressure that would affect the altitude reading in the aircraft, next Air Traffic Control radio frequency, altitude, and airspeed clearance and restrictions). Pilots are taught to deal with all flying tasks under time constraints. Consequently, pilots employ strategies to deal with this large amount of information.

4.2.2 Information strategies

For example, when the pilot is flying a route for the first time, he/she uses a mental picture that he/she has prepared during a pre-flight planning stage. The pilot would expect landscape features to come up at a certain time of the flight and a specific place relative to the aircraft route that he/she will have noted when drawing the flight plan. For a small aircraft it might be lakes, rivers, even a racecourse or a football field, major highways or airports. When the aircraft has gained altitude bigger features will be more suitable for orientation purposes, such as the shape of a town, city, mountain, the shape of a coastline. All of the features on the ground along the route would be expected to come up at the planned time. These are the pilot’s navigational checks. Prior to the flight the pilot built a ‘picture’ of what to expect during the flight and now he/she will constantly compare the expected picture with what is actually seen. Any difference will cause a pilot to check whether he/she is on the right route or has deviated from it.

Information layering strategy
The pilot’s mental picture has many layers, the above describes a navigational layer. This picture would also have a layer of weather, and also the allowed and restricted airspaces. There is also a picture that the pilot expects to see inside the aircraft, for example the fuel gauge should indicate the amount of fuel remaining for that stage of the flight. Depending in which direction the aircraft is flying, the pilot would expect the sun to shine through the cockpit from a specific direction at a particular angle depending on the time of day.

Monitor progress strategy
All the information that the pilot considers during the pre-flight planning stage is on a written flight plan and most of this information is retained in the pilots’ memory. If the pilot has previously flown the route, the pilot would have a picture of the flight and would anticipate a certain feature of the terrain to come up, such as a small town, a river, a major highway, or navigation aids to be on a specific side of the aircraft. The pilot will also anticipate the Air Traffic Control calls to be made. The times at which these anticipated features occur would be an indicator of the current flight progress. For example, a ‘picture’ could be power station smoke rising above the horizon to the right of the aircraft heading, ‘…about now’, the pilot will say in confirmation. If the “picture” that the pilot is expecting to see, does not match pilot’s expectation, it would be a cause for concern.

Navigation recovery strategy
The instructor taught me a navigation recovery strategy. If you realise that the time has passed but, for example, you have not seen the indications of a power station. First, make sure you have the right heading according to the flight plan, then conform that the time that has elapsed is calculated correctly. If you still have a problem, then look at the ground and find a prominent feature, a mountain or a lake for example, determine its shape and find another smaller feature on it or near to it, and then identify your relative position to them. Then locate the same features on the map and mark you position on the map. This would tell you if you had deviated from the course or not. Generally such a situation should not happen, if the pilot is checking his/her position on the map relative to the ground at predetermined equal time intervals, which should be marked on the map prior to the flight.

Scan strategy

Pilots use a scanning technique that is specific to analogue and analogue-like (i.e., can be digital, but still retain an analogue appearance) instruments. The permanent location and the type of analogue instruments determine the strategy pilots use to be aware of aircraft parameters. When the aircraft is established in a manoeuvre, for example straight and level, all of the instruments would remain motionless with a particular indication (e.g. see the four columns of engine instruments in the upper-middle of Figure 4.1 – Hercules C130-H Analogue instrument cockpit). This is exactly what the pilot would expect to see when the aircraft is flying straight and level. The pilot would have a picture in his/her mind of how the instruments should look, and with a quick glance the pilot will be able to determine if this is the case. If there were a discrepancy in what the pilots is expecting to see and what is actually on the display, the problem would be evident instantly. The same strategy would be used across all types of analogue instruments, such as in the example provided earlier about the fuel remaining at each phase of flight.

Figure 4.1: Hercules C130-H cockpit layout (printed with permission from José Jorge).

There is an additional diagnostic tool in a conventional aircraft, a human sense, for example the olfactory sense would pick up if something was burning. The smell would tell a pilot what is burning. A vibration type would give away a possible malfunction. The change in the sound of an engine would indicate to a good pilot, if something were wrong or if the engine is running well.

The instructor taught me to listen for an engine when changing speed and rely on the sound to set the throttles at the right indent, rather then solely relying on eyesight and the setting of the throttle by Revolution Per Minute (RPM) indicator. The reason the instructor insisted on teaching me to use all senses as an indication of change in the aircraft parameters, is because the instruments have a lag in them and generally catch up on indications once the aircraft is established in a particular position, for example, turn or descent. Most importantly, this kind of training is necessary if instruments have failed to give indications of how the aircraft is performing. For example, I will use cues from the outside, such as the horizon and a relative bank to it, rather than using the attitude indicator, to establish required aircraft attitude.

Much of the work the instructor did, is now done by automation and even the flying of the aircraft is now done by an autopilot. Most of the preparations for a commercial flight is done by airline company staff and the checks are carried out by the ground engineers, leaving the bare minimum of checks on the ground to the pilots. Therefore, automation takes much of the workload from the pilot, however, why is there still so much for the pilot to do? Furthermore, why is there so much room for the pilot to make an error?

Above I described examples of building blocks of knowledge, such as basic flight rules and strategies that every pilot has in their professional knowledge. This is the foundation for further pilot training, when he/she will be learning to fly an automated aircraft. This will be constantly referred to in the thesis.

4.2.3 Short introduction to modern automated cockpits

The modern glass cockpit (see Airbus cockpit layout as an example on Figure 4.2 is operated by two pilots in comparison to previous non-automated aircraft where a crew of five: two pilots, flight engineer, navigator and sometimes even a radio operator, operated an aircraft. Therefore, automation has taken over many of the pilot’s tasks, replacing tasks previously performed by a flight engineer, a navigator and a radio operator. Most current automated aircrafts have a Flight Management Guidance System (FMGS) that can be divided into three areas (see Figures 4.4 and 4.5), flight management (also called Flight Management System - FMS), flight guidance (i.e., includes autopilot, flight director and autothrottle) and flight augmentation (i.e., computation and warning systems).

The glass cockpit crew, i.e. the two pilots, communicate with a Flight Management Guidance System (Figures 4.4 and 4.5) through several interfaces. The Flight Control Unit (FCU) provides a short-term interface through which an Autopilot (AP), Flight Director (FD), Authothrotle (A/THR) and all other modes of automation can be engaged. A short-term interface positioned on a glareshield panel allows quick changes to automated system modes. A long-term interface, such as on Airbus 320 that is called the Multipurpose Control and Display Unit (MCDU), is generally used to pre-program the whole flight and to make major route changes. It is positioned between the pilots’ seats on a flighdeck pedestal, near the throttles (see Figure 4.4).

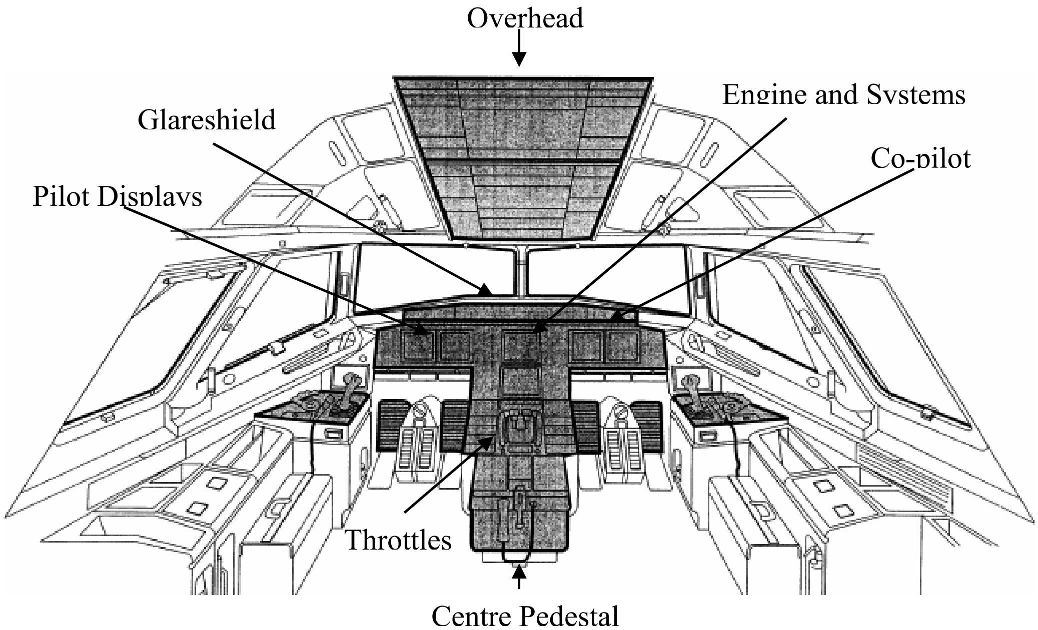


Figure 4.2: Airbus Cockpit Layout (taken from (Airbus_Industrie, 1998) p.2.8)

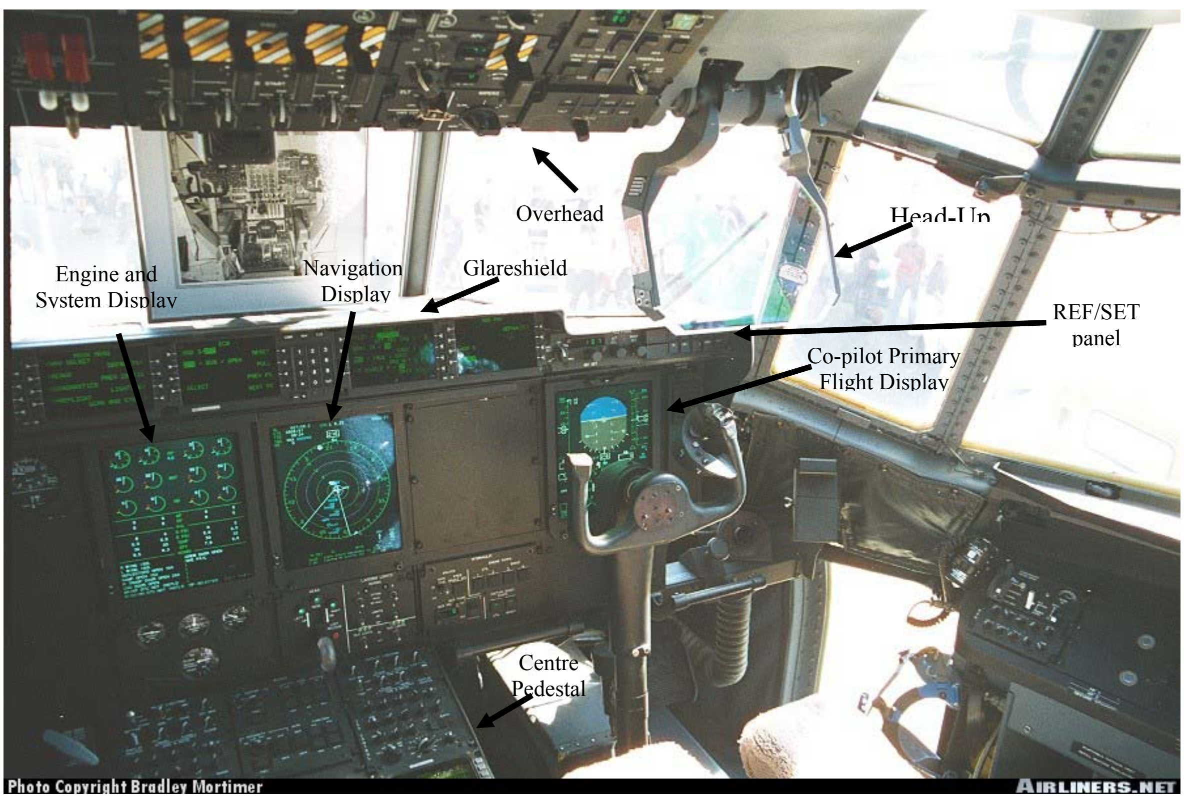


Figure 4.3: Hercules cockpit layout (printed with permission from Bradley Mortimer).

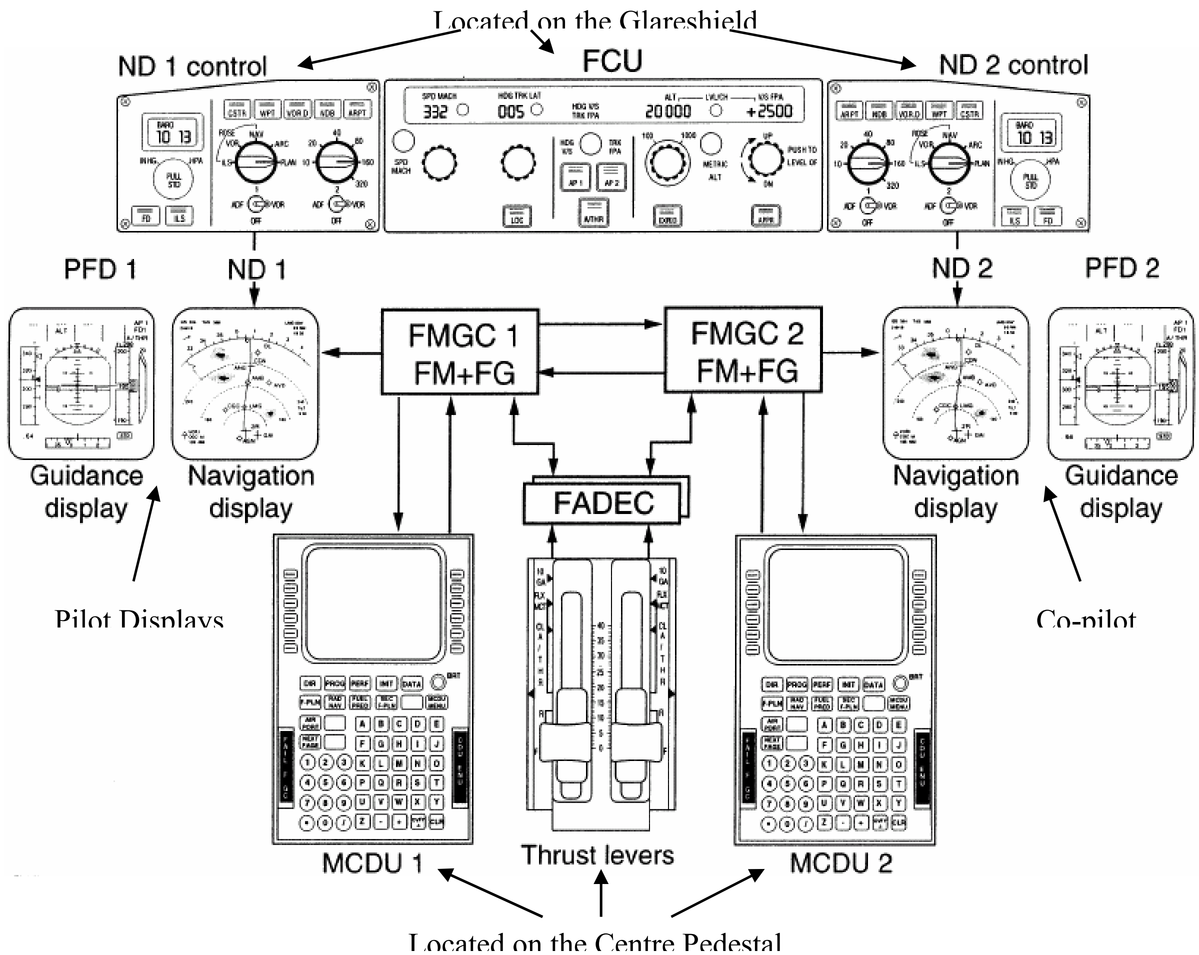


Figure 4.4: Airbus Flight Management Guidance System (FMGS) – Crew Interface (taken from (Airbus_Industrie, 1998) p.10.6)

Generally, a glass cockpit will have a total of six displays, which can be interchanged for a redundancy purpose. Each pilot would have two displays directly in front of them, one a Primary Flight Display (PFD), which is a dynamic colour display comprising all the parameters necessary for flight path control: Attitude, Airspeed, Altitude, Vertical Speed, Heading/Track, Flight Mode Annunciations and Automated Flight System Status. The second display is a Navigation Display (ND) that contains flight route and other related information, such navigational beacons, weather predictions and restrictions, for example en route speed and height restrictions. The remaining two displays, the Engine and System display, are positioned between pilots on the same main instrument panel.

Throughout the flight the Flight Management Guidance System (see Figures 4.4 and 4.5) computes aircraft position using stored aircraft performance and navigational data, steering the aircraft along the preplanned route, vertical and speed profile. An Electronic Centralized Aircraft Monitor (ECAM) system monitors aircraft systems and warns the pilots of any malfunctions. There is also a build-in safety margin, which is called a ‘flight envelope’, that does not allow overstressing of the airframe. The flight envelope would have margins of maximum and minimum speeds, limitations to manoeuvres, such as an excessive 'bank' of the aircraft in a turn. When safety margins are reached a part of the automated program called mode reversion (i.e., change in the state of an automated system) is activated, which returns the aircraft to the safe margins of the flight envelope performance.

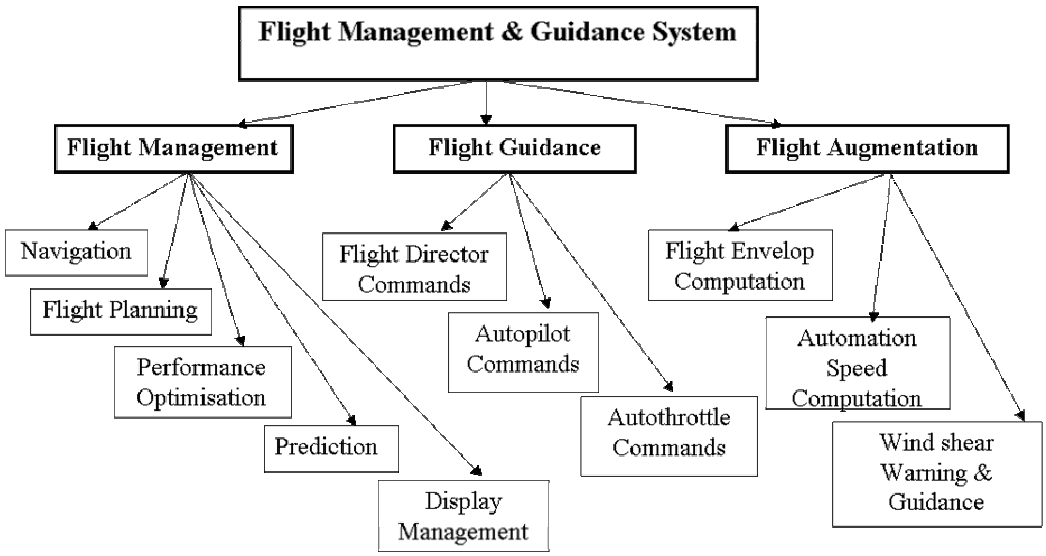


Figure 4.5: Example of typical Automation structure

Last, but also important to understand, is the 'chain of command' in a glass cockpit. The pilot always (almost always, as I will discuss later in this chapter) has control. The pilot programs the flight parameters into the Flight Management Guidance System through a long-term, Multipurpose Control and Display Unit, or if immediate change is required in flight, the pilot uses a Flight Control Unit on the glareshield panel. The Flight Management Guidance System in turn tells the Flight Director what needs to be done, the Flight Director commands the Autopilot and the Autopilot flies the aircraft (see Figure 4.6).

Much more can be explained about the glass cockpit aircraft, but it is not necessary at this stage and as I recall from training I observed, the pilots were also told, "you will understand it later…", as I will be going through practical examples.

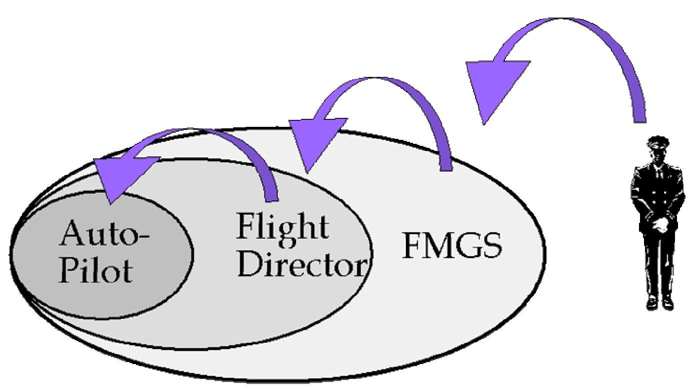


Figure 4.6 'Chain of command' in the Glass Cockpit

4.2.4 Everyday work of an airline pilot and problems with automation

During the observation of pilots’ every day work, it became apparent that pilots have a routine, starting from driving the same route to work, picking up the flight plan from the same office to preparing the cockpit, running through the checklists before and during the flight and even landing at the familiar airport that the pilot flew into yesterday. Pilots are encouraged to use the same procedures not only operating the flight, but the pilots also are encouraged to use the same level of automation at the same stage of flight and engage automation modes in the same way.

This way of operating an airliner is efficient and not likely to be prone to error, however, there are two sides to operating this way. The positive side is that when events do not proceed as expected or the instruments show not what the pilot is expecting, the pilot notices the deviation straight away, but the aircraft has to behave unexpectedly first for the pilot to notice. At times this can be too late for the pilots to make corrections. A negative aspect to this strategy appears when the pilot has to deviate from the routine. This is when errors can occur. For example, as observed in training, when Air Traffic Control requests an altitude change that the pilot has not planned for. The pilot sets up the aircraft (Airbus 320) to climb to 15000 feet of altitude and whilst climbing passing 10000 feet, the Air Traffic Control requests their immediate descent to 9000 feet due to other aircraft traffic. The pilots follow their usual procedure of changing the altitude setting on the Flight Control Unit by dialling the new level-off altitude of 9000 feet and pushing the button to engage the mode to descent. However, the aircraft does not descend and instead keeps climbing, now without a target level-off altitude, because the previous target of 15000 feet was overridden by the new altitude setting of 9000 feet. The 9000 feet is below the aircraft’s current altitude of 10000 feet and the automation program, due to build-in safety features, does not allow the direct transition into a descent if the aircraft has passed that altitude and continues to climb. This is called automation mode reversion. It happened, because the pilot’s input contradicted the pre-programmed logic (i.e., build-in safety) embedded in the programming of automation.

Meanwhile, the pilot is confused, the automation configuration is not as the pilot intended, and the aircraft is flying against the Air Traffic Control’s request. The quickest way to correct the situation is to disengage all automation, manually set the aircraft as required and then reengage the automation.

This is just one example where some pilots are surprised by automation behaviour and loose aircraft control. However, the problem is deeper then a simple surprise, pilots misunderstand automation behaviour and the pre-programmed logic that governs the automation. For example, during the airline operation observations, I observed pilots being confused by automation often, pilots would ask questions such as, ‘what is it (automation) doing now? Why is it doing that?’ A history of well-documented automated aircrafts accidents is an even better testimony to this and it also illustrates the problems with current interfaces that I would like to highlight here.

Human factors experts have been aware of this phenomenon of automation surprise, that is caused by the gaps in pilots’ knowledge about how the automation system functions for many years (see, e.g., Sarter and Woods 1992; 1994). However, from my recent observations of training and line-operation of pilots not much has changed for the last ten to fifteen years, since these glass cockpit type aircraft were manufactured.

Behaviour of automation goes on unnoticed

There is a chain of events and problem types that could lead us to a root-cause of fundamental problems pilots have with automation, where automation behaviour goes on unnoticed. The majority of pilots (80%) responded that they have experienced Automation Surprise at least once during line operation. Other studies on B-757 & B-737-300/400 confirmed this result. (Sarter and Woods 1997)

Problems begin when the behaviour of the automation goes unnoticed for long enough to alter the aircraft position or state significantly, as happened in the Strasburg accident (Strasbourg, 1992). In this accident the pilot on an Airbus 320 intended to enter -3.3 degrees angle of descent for an approach, but instead entered –3300 feet per minute vertical speed descent. This was a significantly steeper and faster descent then the pilot has intended, which resulted in the aircraft crashing into a mountain.

In the above accident the aircraft automation setting was entered incorrectly and altered aircraft vertical position. In another accident, a minor error in the aircraft heading became significant after several hours of flight, altering aircraft position by thousands of miles (Degani, 2004).

Pilot unknowingly effects aircraft behaviour

Another problem occurs when the pilot unknowingly effects the aircraft behaviour, and even worse, tries to work against the aircraft automation. In the case of accidents in Nagoya on Airbus 300 (Aircraft Accident Investigation Commission - Ministry of Transport Japan, 1996) and Moscow on Airbus 310 the pilots unknowingly triggered the TOGA (Take Off and Go-Around) mode. This caused the aircraft automation to add thrust and pull the nose of the aircraft up and as the pilots were not aware of triggering the TOGA switch the pilots were trying to do the opposite, forcing the aircraft to descend, as they planned. This caused the automation to trim the aircraft to keep the nose-up, which in turn made it impossible for the pilots to control the aircraft, which resulted in the aircraft stall and crash (Billings, 1997).

In a Bangalore accident (Ministry of Civil Aviation, 1990) a similar type of problem occurred, only in this case the pilots instead of engaging the unwanted mode, did not properly disengage the Flight Director. The aircraft struck short of the runway, because the pilot disengaged only one Flight Director and unknowingly still had one Flight Director on, which kept the aircraft in the Open Descent Mode without an altitude level off target.

The problem in all the above accidents is that the automation had masked the onset of the problem and the pilots were unaware that the automation's 'intentions' were different to their intentions. From the pilot's point of view the automation was performing as intended and the problem showed itself too late for the pilots to correct it. The list of accidents I mentioned here relate to the same problem and are not an exhaustive list. It is a recurrent problem that starts when pilots begin their training on an automated aircraft.

I want to investigate where the problems and inherent contradictions in logic between the pilots and automation-assisted flight occur. It would appear appropriate to start searching at the level of pilot training.

4.2.5 What pilots must learn and re-learn when converting to an automated aircraft

Five issues stood out throughout the observation of training conversion courses from a conventional analogue instrument aircraft to fully automated glass cockpit (i.e., a cockpit that contains several displays that resembles glass surfaces, hence the name a 'glass cockpit') aircraft:

- Pilots rely and build upon existing knowledge
- Pilots use of visual scanning techniques
- Pilots use different operating strategies to the automation
- The behaviour of automation is masked
- Reliance on memory, but too many 'ifs' and possibilities are pre-programmed

1. Pilots build on existing knowledge:
During training pilots struggled to understand the logic and philosophy behind the design of automation. Pilots constantly were asking, "what is it doing now; why is it doing that?" To relate to and to better understand the new automated aircraft pilots were trying to relate the new information about the operation of the automated aircrafts to the operation of the aircrafts they had flown previously. Training experts also observe this during conversion courses (Baxter, 1998). Additionally, they repeat that pilots with extensive experience on conventional type aircrafts try to understand and even operate a new automated aircraft by analogy to a familiar aircraft. From my observations of training, pilots would even resort to the very basics of flying, if they could not find a similarity with the operation of an aircraft they had previously flown.

Unfortunately for pilots, the operation of modern automated aircrafts has little resemblance to the operation of a basic aircraft (Billings, 1997), as I observed during the training. At times during the conversion course, it seemed that the instructor was teaching about a new breed of craft, rather than a more automated conventional fixed-wing aircraft.

2. Pilots use of visual scanning techniques:
Pilot were trying to use previous knowledge in the new automated cockpit, and also trying to use instrument scanning techniques that they used in conventional cockpits with analogue displays. The instrument scan used in a conventional cockpit is an efficient method for being aware of any changes because all, or most, instruments are 'analogue'. This allows instruments to be scanned like one picture rather then reading each individual instrument. For example, engine indications are presented in columns with various indications in rows, such as oil pressure and oil temperature, where each column shows indications for a specific engine (see Figure 4.7 Analogue engine indications).

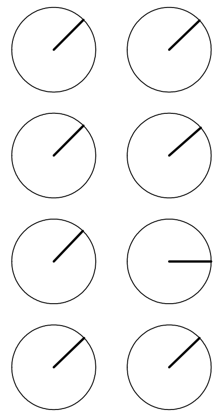


Figure 4.7: Analogue engine indications

In a conventional scanning technique, the direction and rate of pointer movement for all instruments is checked at regular intervals in order to quickly detect any undesirable changes. This allows pilots, at a glance, to confirm that all pointers are at their expected positions, and changes are occurring as predicted. The figure shows the third instrument in the second column having a distinctly different reading to the other instruments, prompting the pilot to investigate further (see Figure 4.7).

However, the problem with this type of scan in an automated cockpit is that the information is presented mostly in an alphanumerical form. Hence, a simple glance is not sufficient to detect change or abnormality, further reading and interpreting of data is required.

In an automated aircraft the pilot needs to monitor and verify any changes in the system by reading data. For example, a mode annunciation is represented by an abbreviated selection of letters, which establishes what the aircraft automaton is doing, at this point the pilot has to read at least three abbreviations to check where the data is being taken from by the automation, and then put it all this data together in his/her mind.

The conventional scan is not effective when pilots need to deduce the state the automation is in. There are generally three possible types of modes, autothrottle, vertical and lateral (see the top of the Primary Flight Display Figure 4.4 and Figure 4.8), plus annunciation that the Autothrottle, Autopilot and Flight Director are engaged or not. Each mode is announced in an abbreviation of two to six letters, divided by a vertical line. A conventional scan of analogue instruments will not help a pilots deduce the state the automation is in, because a simple glance will only tell how many modes are announced and possibly how long is the name of each mode. This would have been sufficient in an analogue instrument scan, where the pilots would determine the position and direction of each indicator, possibly relative to other instruments indicator positions. When the pilot scans, the conventional way, the names of automation modes (see Primary Flight Display Figure 4.4), there is a possibility that the pilot would not capture the meaning of each mode or even make mistakes for modes with similar abbreviations, for example those that begin with the same latter and have similar number of letter.

In the first case, when scanning analogue instruments a pilot is looking for a pattern; in the second, a pilot is problem-solving using the available data, which takes more processing time. For example, pilots in training that reverted to using an analogue instrument scanning were missing important information, on automation mode changes.

Airbus philosophy suggests its own strategy for monitoring automated aircraft, "A proper monitoring of FMGS (Flight Management and Guidance System) requires a minimum understanding and to always keep in mind two questions: What do I want the aircraft to fly now? What do I want the aircraft to fly next?" (p.40, Airbus Industrie, 1996). This is a more effective strategy in an automated aircraft than the scan pilots' use in a conventional cockpit, because it allows the pilots to search for answers in the available instrument data, rather than for patterns. Patterns are not obvious in an automated aircraft and so need to be 'generated' in the pilot's mind and only then compared.

This technique (Airbus Monitoring Strategy) resembles a 'rule' that pilots are taught to follow early on in their flying lesson, '*a pilot should be always be ahead of the aircraft'*. However, there is a problem with Airbus's suggested strategy, it is difficult to implement. The design of automated cockpits does not allow pilots to answer these questions easily. Pilots have to scan relevant instrument readings, identify and read annunciations about the automations state from several locations (Flight Control Unit and Primary Flight Display for example), recall the flight plan and restrictions associated with the current stage of the flight, and then deduce the answer to the posed questions. There is minimal pilot support for this type of monitoring that requires problem solving in a current automated cockpit.

3. Pilots use different operating strategies to automation:
According to human factors experts, to avoid the common problem of automation surprise on automated aircrafts, the pilot should be alert to any changes in the automated system (Sarter and Woods 1997). From the discussion above on scanning and monitoring strategies this appears to be difficult to achieve this in a current automated cockpit. Additionally, this is also compounded by another set of problems that makes these tasks even more challenging.

The behaviour of automation, although presumed in the 'philosophy' (Tarnowski, 1999; Airbus Industrie, 1996), in many ways does not resemble the actions of a pilot. That automation does not behave or respond like another crew member, is a crucial piece of information and was not emphasised enough during the conversion course I attended. In fact, the reverse was true. During observation of the conversion course training there were three major issues about the automation behaviour strategies that stood out as being different to pilots' strategies. Several examples are discussed in this section.

The core of these issues is that pilots use different strategies to those of the automation to deal with the same problems:

(a) The activation of automation functions may be in an awkward or unnatural order.
(b) Automation may not respond in the same way as a pilot would respond.
(c) Automation may fly the aircraft differently.

(a) **The activation of automation functions may be in an awkward or unnatural order**, for example, pilots found it difficult to remember the location and the sequence of pages that they had to follow in order to bring up a specific page during a particular stage of flight from the Multipurpose Control and Display Unit on the Airbus 320. The Multipurpose Control and Display Unit is a computer that consists of several electronic pages, specific to phases of flight and system state. An associated problem is that the information that the pilots would be looking for, would change place, for example the information would be moved to a different page and a different location on the page, depending on the phase of flight. The trick to bringing up a secondary flight plan page in flight on the Multipurpose Control and Display Unit is to switch to HDG (i.e. heading) mode from NAV (i.e. navigation) mode in order to have a prompt to activate the secondary plan in the Multipurpose Control and Display Unit. The pilot needs to use a different control panel, the Flight Control Unit, to switch to HDG mode and see the annunciation of the mode on the Primary Flight Display before brining up the secondary flight plan on the MCDU (see problem 80, Appendix 2, Airbus).

(b) **Automation may respond differently than the pilots would**. Good examples are the mode reversions that exist on Airbus 320 as a part of the flight envelope protection. Ordinarily, if the pilot is manually flying the aircraft and observes that the aircraft cannot maintain the desired speed in a climb, the pilot would either select to fly at a slower speed or reduce the angle of attack. However, when the automation cannot maintain the speed during SPEED mode and is in V/S (i.e., Vertical Speed) mode with armed ALT (i.e., altitude) mode, the automation reverts to two new modes, the THR CLB (i.e., Thrust Climb) mode and the OP CLB (i.e., Open Climb) mode (see Airbus Industrie, 1996 and Ansett Australia, 1997 for further examples). In this new mode configuration the automation changes not only behaviour, but also the aircraft's climb trajectory, and disregards the pilot's commanded vertical speed and will not reach a given altitude by a previously requested distance. It could violate a restricted airspace or in the worst-case scenario, it could be heading for another aircraft or the terrain.

The problem with this type of mode reversions is that the automation tells the pilot *after* it has changed itself and only with the bare minimum of information, 'I am maintaining speed during climb.' It does not tell the pilot why it changed it or that it is deciding to change it. The pilot now has to remember, which modes the automation was originally flying in, what has caused the change and then consider the effect of a new change, meanwhile possibly heading towards a collision.

A similar scenario could happen in descent, but produce an even more surprising behaviour on the part of automation. For example, if the ALT (i.e., Altitude) mode is not armed, the automation would not only change the aircraft's behaviour in the manner and trajectory in which the aircraft is descending, i.e. from maintaining a vertical speed to a specific speed on throttles, but it will in fact make the aircraft go into a climb.

These are just two examples of where pilots can be surprised by automation behaviour. However, the problem is deeper then a simple surprise. Pilots misunderstand the behaviour and the logic that govern the automation, because it is different and does not resemble what pilots do.

The observations of training showed that pilots do not find 'automation logic' intuitive. Pilots find that automation does not follow the same logic as pilots when operating the aircraft. When confronted with unfamiliar situations, such as described above, they do not know what to expect, and are genuinely confused by responses and actions of automation.

(c) Automation would fly the aircraft differently and does not take responsibility. A good example (see problem 68, Appendix 2, Airbus), from an Airbus 320, of automation operating an aircraft differently is when the pilot would like to increase the rate of descent, he/she would use the speed breaks. However, when flying with an automated aircraft pilots are advised not to use speed breaks to increase the rate of descent, because when automation is engaged in a V/S (i.e., Vertical Speed) or a FPA (i.e., Flight Path Angle) mode this action would only lead to an increase in thrust, which is exactly what the pilots want to avoid (Also, see the same type of problems in the Appendix 2, problem 96).
Another example that makes the automation flying the aircraft fundamentally different from how pilots fly it, comes again from the Airbus 320 (see problem 72, Appendix 2, Airbus). The automation has a different strategy to the pilot during descent, the pilot controls speed by pitch (i.e., this implies no change to thrust), but the automation controls speed by changing thrust.

Pilots' conversion course did not stress enough the fact that the automation does not act as a pilot, and it should not be relied on as another member of the crew. It is only a piece of programming that has the limitations of a program, i.e. it only has the logic that the programmer put into it.

The program does not posses human qualities, such as a responsibility to tell the pilot that it would only do the task partially, or that under these circumstance it can not perform the required task well, such as in an accident. Further, it does not have sense of responsibility to complete the task and save the crew from a disaster. Yet when pilots engage the automation in a particular mode it is with the assumption that it would imitate the behaviour of another pilot flying. The pilot engaging the automation would transfer not only the action, but also the responsibility to the automation. As a result misunderstandings, surprises and something similar to 'betrayal' happens. For example, (see problem 33 in the Appendix 2) if the pilot is to tell a co-pilot to conduct a Go-Around procedure on a Hercules aircraft, the pilot would engage full throttle, point the aircraft 7 degrees nose up, wings level and keep a runway heading. However, when the automation is engaged in Go-Around mode, it would do the bare minimum only. The Flight Director would give a cue for 7 degrees nose up and wings level, but instead of engaging, the Autopilot it would disengage it and all other FD modes. This is also not the only the case that the automation does not take the responsibility. It does not do the action the pilot expects, it also disengages all previous automation settings at a critical point of the flight and it does not explicitly tell the pilot about its actions.

The problem with this kind of a situation is the assumption, on the part of the pilot, that it is the same as passing on the responsibility to the automation to conduct a go-around as if passing this to another member of the crew. The automation is limited by the program and the automation does not have responsibility, this feature is not programmed. The problem is not only the fact that the automation failed to take the responsibility, but that this is not communicated to the pilot.

This problem begins when automation modes are named after the action that the pilot would otherwise have done differently, and in most cases significantly differently. From my observations pilots converting from a conventional aircraft were often confused and did not understand why the automation did not finish or did not perform, a part of the procedure that they as pilots certainly would have done in a given situation.

Probably out of frustration and difficulties of teaching pilots the many ways in which the automation can be made to perform the same function, and under which conditions, the instructors would tell pilots the most terrifying response, mostly as a last resort, "Do not worry, it will become clear when you will start operating the aircraft as a line-pilot." This is in fact a common practice to teach pilots during a line operation, a 'hands-on' experience, but in earlier generation of aircraft perhaps pilots had no problem reading the displays or pushing corresponding buttons. Today pilots have difficulty understanding the philosophy behind the aircrafts operation and the logic behind operation of these aircrafts, which as it was observed are crucial to safety in line operation.

One of the pilots on the course used to fly an Airbus 320, but even though he was a captain on this aircraft for several years, two years prior to this refresher course, and had flown a different aircraft since, he had been caught by automation surprises during this conversion training program. The interesting fact here is that none of the pilots had forgotten the fundamentals of flying learned ten to twenty five years ago, but this experienced pilot had forgotten something learned about a glass cockpit aircraft just two years ago. This issue is discussed in chapters 6 and 7, on how some information is easier to remember and recall than others.

4. Behaviour of automation is masked

Automation behaviour is not always announced to the pilot. This does not help pilots learn about the automation while they are operating it on line. For example, during an Autoland, LAND3 mode, if a crosswind is present, the runway alignment starts at 500' to 200' radio altitude and the automation is compensating with a rudder adjustment for any wind blowing across the runway, the correction to a crosswind is not announced to the pilot (see problem 40, Appendix 2, Boeing 777). In a situation where the pilot has to takeover from the automation into a manual operation the pilot would not be aware of all the actions (e.g. amount of rudder pressure) that the automation was performing. Consequently, the pilot does not apply the right amount of pressure to the rudder pedals, the aircraft could make a violent manoeuvre from which it may not recover, if it is too close to the ground.

5. Reliance on memory

A fundamental problem with the above issues is that pilots have to rely on their memory, which is not a human strength (Wickens and Holland, 2000; Billings, 1997; Amalberti, 1999) and possibly is an area where pilots should have help from automation.

Like any program the automation works on conditions, also called, *if – then – else rules*. Although the program works perfectly following these rules, the pilots find it difficult to remember all the *Ifs* influencing conditions, while operating the aircraft. There are several categories of *ifs* that I came across in manuals and during training.

One category relates to the operation of the same switch under different conditions that would give a different response in various situations. A TOGA (i.e., Take Off and Go Around) switch for example (see problem 36 and also see problem 43, Appendix 2 Boeing 777) can have different actions and responses. During take off if LNAV (i.e., Lateral Navigation) or VNAV (i.e., Vertical Navigation) modes are armed, the push of a TOGA switch will disarm LNAV and VNAV, leaving the pilot without the navigational data for the automation to follow in order to continue the flight. The same switch will not disarm itself (see problem 37, Appendix 2, Boeing 777) if the speed is not lower than 80 knots, and if FD is on and LNAV and VNAV are armed, pushing the TOGA switch would disarm the LVAN and VNAV. To confuse matters further if the TOGA switch is pushed twice it will set the throttle at full thrust.

In the same example there is yet another problem that of the consistency (i.e., discussion in full later) of a function across the function of all buttons, this is discussed later in this chapter. The problem is that generally the second push of a button would disconnect the function of a button, but in this case it will do the reverse, setting the thrust to full.

Another category is when the automation can or cannot be engaged or disengaged *If* a particular condition is present or absent. For example, (see problem 39, Appendix 2, Boeing 777) if the automation is in an approach mode, the APP (i.e., Approach mode) button cannot disconnect the APP mode, if the LOC (i.e., Localiser mode) and G/S (i.e., Glide Slope mode) is engaged. To disconnect the approach in this situation the pilot first has to disconnect the Flight Director and only then will the APP button disconnect the approach mode.

In other cases the APPR (i.e., Approach mode) will also not engage if the pilot engages it too late. A survey of forty-six experienced pilots responded that 28.3% of themselves and 30.4% saw another pilot 'tried to engage APPR too late so that it failed to capture' a signal from navigation aids (Demagalski, J. et al 2002).

A further problem on Airbus 320, falls under the same category (see problem 70, Appendix 2). If the pilot did not enter specific data prior to take off, the FLEX TO mode will not engage during take off even if the thrust levers are in FLX TO/MCT detent provided. To operate correctly, data such as, a FLX temperature, has to be entered through the Multipurpose Control and Display Unit prior to take off in order to activate this mode.

The conditions under this '*if* category' are countless and too many to remember or probably even to name during training. They can appear in everyday operations, for example (problem 71, in the Appendix 2), if the Flight Director is off the pilot cannot manage the airspeed apart from if in the APPR mode. Pilots have to rely on their memory to remember the conditions under which the automation will or will not engage and, in an emergency situation the correct recollection of the 'if conditions' could be crucial.

A bigger problem is that the '*if* conditions' become crucial to recall and understand the reasons behind the automation's behaviour. This is especially so in a deteriorating situation, for example loosing altitude (see problem 89, Appendix 2, Airbus 320). For instance, during climb if the ATHR (i.e., Autothrottle) is engaged the aircraft will come back to an approach speed, which will generally be too low and stall an aircraft. This can cause a critical situation if this happens during a go-around where there is not enough altitude to recover from a stall before crashing into a runway.

The above examples illustrate the challenge pilots face when converting from a conventional to an automated aircraft. The pilots not only have to learn a new way of operating an aircraft, but they need to be aware and remember that the automation does not always respond like their fellow crewmembers under similar conditions. Pilots have to largely rely on their memory, to recall the various ways to set up (i.e., prepare an aircraft) for a particular manoeuvre and, know the effects that this manoeuvre can have on the aircraft automation, whilst being aware of the flight envelop protection laws and not breaking them. Pilots have to remember how to exit from an automated mode of operation correctly, otherwise it could result in an accident, as in the case of Bangalore accident (Ministry of Civil Aviation, 1990), where the pilot failed to disengage one of two Flight Directors. To add to the challenge, pilots have to do all this with minimal or no help at all from the displays.

4.2.6 'Tricks of the trade' from Instructors and Experienced Pilots

Instructors come up with 'tricks' to give pilots in training to help them remember some of the '*if* conditions' or the sequences of executing a procedure on an automated aircraft. The instructor suggests an easily remembered abbreviation, such as ABCD, where each letter is the first letter of an action to be executed for a non-precision approach, where *A* is for requesting weather from *A*TIS (Airport Terminal Information System) plus a set up of the Flight Management and Guidance Computer, *B* is for *B*riefing the crew for an approach, *C* is for *C*hecklists, and *D* is for a *D*escent scan of instruments. Problems exist with activating an approach, which is a critical issue, as according to a survey of pilots flying Airbus 320, there is approximately a 20% chance that the crew will fail to activate an approach (Sarter and Woods, 1997).

However, as witnessed during the conversion training in which I participated, the 'trick' of abbreviation did not work well. Pilots forget to set the Flight Management and Guidance System because it is not a part of the abbreviated letters and came under the letter A, after calling for *A*TIS. This, is the step that pilots forgot to set, and it is precisely this step that is the reported problem in the survey of Airbus pilots mentioned above (Sarter and Woods, 1997).

Some pilots invent their own ways of using glass cockpit displays to help them with either monitoring or controlling the aircraft. However, these are not the intended practices of the interface design engineers. One Boeing pilot stated that he uses Vertical Speed Indicator on the Primary Flight Display as an indicator of the descent angle during an approach, even thought it is not designed to show this.

There are so many tricks that are used in operation of current automated aircrafts, that one can write a whole manual. There is even a web community (www.bluecoat.org) that is dedicated to the exchange of problems that pilots face in everyday operation. Pilots, that belong to this community, exchange several emails a day sharing problems and suggesting solutions to each other.

4.3 Identification and Classification of problems

The scope for research and investigation of the problems related to new types of automated aircraft is vast, especially when two types (i.e., commercial and military) of aircraft and from three different manufacturers (i.e., Lockheed Martin, Boeing and Airbus) are involved. The comparison discussed in this chapter between the cockpits show how one manufacturer solved problems that exist in a competitor's cockpit, and the common traits of problems exist among all automated cockpits.

There are several problem areas, as can be seen from a problem table (Appendix 2), although important, I have not focused on all of them, such as the use of colour in mode annunciations. This may be part of future research.

The vast number of problems on automated aircraft that I came across while conducting this research can be classified into a well know classification system or taxonomy that was suggested by the team of researchers that undertook the important task of bringing together all currently known problems in automated aircraft by analysing research literature, questionnaires, incident and accident reports (Funk and Lyall, 1998). For the purpose of scoping my research I used their 'Alternative Taxonomy of Flightdeck Automation Problems and Concerns'. It shows the type of problems I was interested in and how they are distributed across three different automated cockpits.

The Alternative Taxonomy is divided into five sections, Automation-Centered, Pilot-Centered, Crew-Centered, Organization-Centered and Other Problems and Concerns (http://www.flightdeckautomation.com/phase1/phase1alttaxonomy.aspx). Each section is further divided into several categories. The first two categories are the most relevant to the problems identified, but not all subcategories were used, for example, under the Automation-Centered category, the subcategory, Automation Failure, was not used. This category is not the focus of my research, as I am more interested in how to make pilots aware of when the automation fails. Similarly, the section Pilot-Centered was not used, for example 'underconfidence' and 'overconfidence' categories, because this was not the focus of this research.

Funk and Lyall's descriptions of each category were followed as closely as possible, however, some problems could be classified in several categories depending on the point of view taken on the problem. Some subcategories can include other subcategories, depending upon what is seen as a problem. For example, the subcategory 'automation behaviour may be unexpected and unexplained' can also belong to the 'automation awareness' category in the main section of the 'pilot-centered problems and concerns'. In this classification scheme it is not important or at least not helpful to classify the problem differently as it will not help to solve the problem. In contrast, the matrix that I suggest in chapter six and seven may help with a solution to the problem once the problems are 'classified or identified' and related to a specific category.

It is considered that the classification of problems, such as the taxonomy described above should also be helpful in identifying the root of problems, but in fact is not in all cases. This is evident in the Alternative Taxonomy (Funk and Lyall 1998), which can show that problems at pilot-centered level have roots at the automation-centered level. For example, a total of 18.7% (out of all flightdeck automation problems) of all the problems that pilots face, which include understanding (4.2%), use (2.8%), automation awareness (6.5%) and situation awareness problems (5.2%) can be solved at the automation level under the category of pilot/automation interface. However, the category of pilot/automation interface only accounts for 12.9% according to Alternative Taxonomy problems. This category, pilot/automation interface, should also account 18.7% of pilot-centered problems, because this is where the problems are rooted, as we already observed in discussion of problems at the beginning of this chapter.

For the reason mentioned above, that some problems could fit under more than one category, and because I had an interest in specific problems, I had placed more problems in some categories than others. This biased classification, according to my research focus, shows where the problems of interest to me are located in a well-recognised taxonomic format. The volume of problems differs between the three aircraft, but these are mainly because I had more access to the documentation of the Airbus and Hercules, than to the Boeing documentation. This is not an indication that one type of aircraft has more problems than the other. The problems classified here are from training that I observed and participated in, from the airline operations, and from manuals on all three aircrafts. The full taxonomy can be seen in the Appendix 2.

4.4 Consistency as a category in listing automation related problems

I have already discussed examples of problems from each of the categories in this chapter, but for further information on, or to have a more comprehensive view of existing problems in information presentation in a glass cockpit, please refer to Appendix 2. The most common problem across all cockpits as observed in line-operations, during training sessions and from reference to manuals, which is not a part of category in the Alternative Taxonomy, was related to *consistency* issue in design on several levels: the use of buttons; the spatial location of information across panels and similar displays; the format of information presentation; the behaviour of automation is not consistent with pilots' behaviour; and in the application of philosophy throughout the design.

There are strong cases both for (e.g., Shneiderman, 1987) and against (e.g., Grudin, 1989) consistency as a design principle in an interface design. Grudin (1989) argues that as more user tasks, and more of the user's environment are understood, the further away from consistency the interface design shifts. For example, in a safety-critical domain, locating the appropriate command to activate or deactivate the system is time-critical. An example of a consistent 'activate/deactivate' interface design might be considered as the established menu structure in Microsoft programs that dictates that an 'exit' (i.e. deactivate) function appears toward the end of the drop-down menu entitled 'File'. However, if this design approach were to be taken in a time critical system it would be seen that to use the exit command takes several steps (i.e. several seconds). In such a system a split second saved by a 'deactivate' function being a separate selection, and accessible instantaneously no matter where the user is in the program, may have priority above consistency. In this case, rigidly following a rule of consistency of menu structure may not be appropriate. However, consistency of information layout that minimizes user's time spend searching is also safety critical. Hence, "consistency and other design rules are best seen as guidelines that may have to be violated for the benefit of users" (p. 103, Grudin, 1992).

In this part of the chapter, the consistency as a design guideline in a glass cockpit is assessed as being useful or disadvantageous.

4.4.1 Poor consistency in the use of buttons and knobs

There is poor consistency in the use of buttons and knobs for functions. The push of a button generically means putting something ON. In the Airbus 320 cockpit it could mean three things: arming (i.e., on, but not active), engaging (i.e., on and active), disengage (i.e., completely OFF) and some buttons, as discussed earlier (similar problem (43b, Appendix 2) on Boeing) in Boeing 777 cockpit need to be pushed twice to set its function at a maximum (for example a full thrust). A similar problem also exists on the Airbus (see problem 92 ‘similar buttons have contradicting functions’, Appendix 2 Airbus). In a time-critical situation this could become a problem, for example, if the pilot is attempting to disengage the Autothrottle he/she could instead set the Autothrottle to a full thrust. This would do the opposite to what the pilot intended, it would surprise the pilot and put an aircraft in an undesired state.

When considering a design of switches for operations of safety critical functions there is a need for consistency in operation. For example, if selecting a pushbutton for activation and deactivation of the system, the two opposite states (i.e., pressed and depressed) should only be used. These two states give a tactile and visual feedback of the system’s state. If any deviations in operation of the pushbutton occur, such as pressing the button when the system is in a specific state that result in other then active and deactivate state, or pressing the button for a longer periods, it has to be clearly indicated to the operator prior the selection of the state. For example, the menu with current and the following state can be shown or a three-position switch with clearly marked selections can be used instead of a pushbutton.

To complicate matters further in a modern cockpit, the knob on the Mode Control Panel can select the desired value by rotating the knob, then the pilot can arm or/and engage either the managed mode (i.e., derived from Multipurpose Control and Display Unit) by pushing it or by pulling it to activate a selected mode (i.e., derived from the pilot’s entry). In the survey by Demagalski and collegues (2002), forty-six pilots responded that 26.1% of themselves or 26.1% saw another pilot ‘having entered the desired airspeed pushed or pulled the switch in the opposite way to the one that you wanted’.

There are also buttons with a similar label that appear to have the same function, but actually they do not follow the same operational logic. Similar switches work differently on the Mode Control Panel. The ALT (i.e., Altitude) switch can be switched to ‘AUTO’ or to ‘1000’. The ‘AUTO’ indication means that the switch has a rate sensitive rotation, a slower rotation will increase altitude by small increments, and a fast rotation will increase altitude in higher increments. However, the ‘AUTO’ position on the BANK switch means the bank of the aircraft (as an action) is limited by the Autopilot, plus the same switch also sets the bank angle (see problem 45, Appendix 2, Boeing 777).

In the above case the label ‘AUTO’ is not used consistently. In two cases, ALT and BANK, it represents two different things, the ‘automatic’ switching between fast and slow increments in the value and ‘autopilot’ function of limiting the angle of bank, respectively. The abbreviation selected to describe the functionality needs to be more accurate, representative and not clash with other generalised abbreviations that can be interpreted in several ways. Consistency in the labelling of buttons and switches is essential in this case, as it reduces the need for unnecessary memorisation of the varied meanings behind the same abbreviation.

In addition, the ALT button has other contradicting functions. Pushing the ALT switch on the Mode Control Panel executes the altitude entered, but the same button also deletes the altitude restrictions entered in the Flight Management Computer (Problem 48, Appendix 2 Boeing 777). The only difference in the outcome of an action (i.e., press) is the different conditions under which the button is pressed, which again have to be remembered by the pilot.

The selection of appropriate function is also difficult when the pushbutton labels are inconsistent on the same panel, for example on the overhead panel. The Air Bleed overhead panel has two rows of buttons. All buttons are divided into two parts and each part of the button is illuminated to show the current selection. The top row has the ‘AUTO’ lit up on the top part of the button. The bottom row however, has the ‘ON’ sign at the top on the two buttons, and one button has the ‘AUTO’ sign. Moreover, although the top of the buttons are not consistent, all of the buttons on the second, lower part of the button, have an ‘OFF’ sign, which is consistent across all the buttons on this panel. A problem is that the pilot can only see the illuminated selection and cannot see the other half, because it is not illuminated. If the pilot would choose to follow the sign’s logic on the rest of the buttons, the pilot can mistake between an ‘AUTO’ sign for an ‘ON’ (problem 51, Appendix 2 Boeing 777).

The overhead panel buttons are made dark with the intention to maintain ‘the dark philosophy’ cockpit, which means if nothing is illuminated there are no problems. This, however, as it can be seen from the above example, can make the selection of the correct function difficult, because it does not allow the alternative selection to be seen. In this case consistency in assigning functionality to the pushbuttons is safety critical. For example, all functions need to be consistently positioned either at the top or at the bottom of the pushbutton or if consistency cannot be applied in this part of the panel, they need to be clearly labelled in both states, an illuminated and a non-illuminated state.

4.4.2 Name on the button is not consistent with the selection name

To add to the confusion the pilots already have a lot of information to commit to memory about how the automation operates under various ‘if’ conditions. There are buttons in the cockpit that have names that do not reflect the selection of their function. For example, some buttons on the REF/SET mode panel do not always correspond the annunciation on the Mode Annunciation Panel and Primary Flight Display (Solodilova, Lintern, & Johnson, 2005). The selection of a button ‘NAV ON’ on the REF/SET panel announces ‘NAV ARM’ (i.e., Navigation Armed mode), but the button ‘APPR ON’ on the REF/SET panel announces ‘GS ARM’ (i.e., Glide Slope Armed mode) on the Primary Flight Display. Similarly, the selection of the ‘SEL ON’ button brings up an ‘ALT SEL’ (i.e., Altitude Select) mode on the Primary Flight Display (problem 24, Appendix 2, Hercules). Although, the consistency in the corresponding annunciation on the Primary Flight Display when selecting ‘NAV ON’ and ‘APPR ON’ are not as ambiguous as the ‘SEL ON’ mode, which does not provide any cues to what mode it will select. This type of labelling is not consistent with other modes labels rationale, and again leaves the burden on the pilot to memorise the corresponding function through vague abbreviation.

4.4.3 Information layout is not consistent

Information layout is not consistent across all panels and displays. The layout of information on the Primary Flight Display is not consistent with the layout on the Mode Control Panel. The instrument layout on the Primary Flight Display is in the following order - Autothrottle, Heading, Altitude and Vertical Speed, but the order on the buttons on the Mode Control Panel is Autothrottle, Heading, Vertical Speed and Altitude, i.e., the last two selections are in reverse order (problem 38 in the Appendix 2, Boeing 777). This inconsistency can cause the pilot to select an incorrect function on the Mode Control Panel. In a survey of forty-six pilots 78.3% responded that they themselves or 65.2% saw another pilot 'adjusted the heading knob instead of the speed knob' (Demagalski, et al 2002). These incidents of erroneous selection can potentially be reduced through promoting consistency of order of annunciations on displays (i.e., Primary Flight Display) and panels such as the Mode Control Panel. A similar problem exists on the Hercules (Problem 6, Appendix 2, Hercules) and Airbus (Problem 65, Appendix 2 Airbus 320) interfaces.

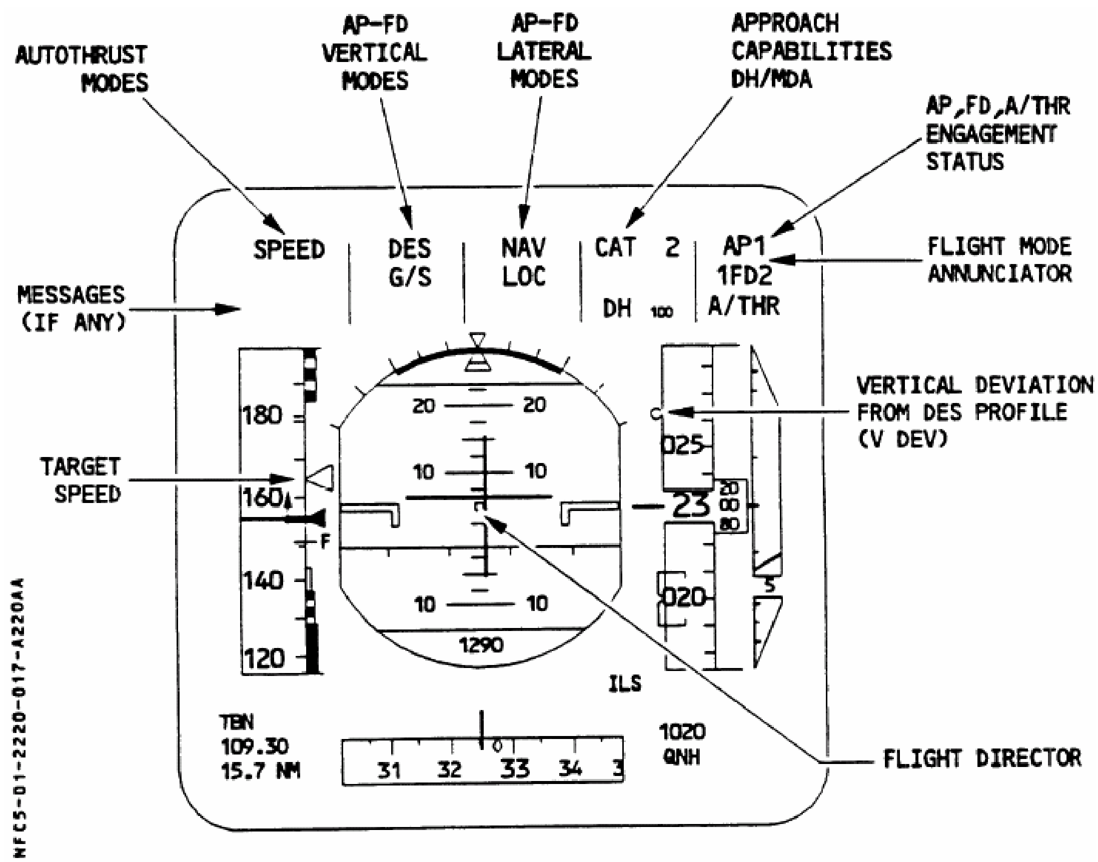


Figure 4.8: Airbus Primary Flight Display (taken from (Ansett Australia, 1997) 1.22.20 p.17)

The order of information presented also differs on the same display. On the Primary Flight Display (see Figure 4.8) the automation mode annunciation is in the following order: Speed, Vertical and Lateral (heading) mode; however, instruments on the same display are in a different order: Speed, Heading/Attitude, Altitude and Vertical Speed. This means that the related instrument is not located directly under the name of the mode within the same display (problem 64, Appendix 2, Airbus 320).

In this case the consistency in the order of instruments and corresponding mode selection on the panel and the display is appropriate and will save pilots' time to locate the information required, as well as training time.

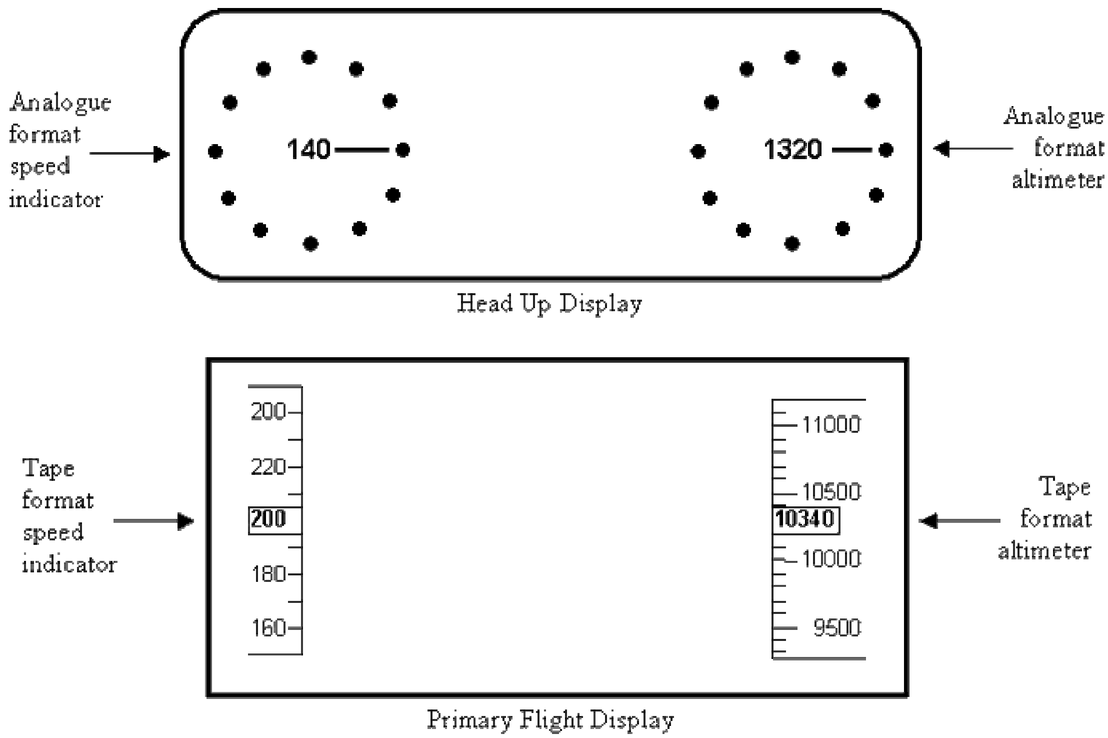


Figure 4.9: Tape and Analogue format of Speed and Altitude presentation

4.4.4 Consistency in the format of information presentation

There is also inconsistency on displays of the same type, in this case a Primary Flight Display (Problem 28 in the Appendix 2 Hercules). The same information, the altitude, speed and compass are presented in different formats. On the Head Down Display (Figure 4.9) the altitude and the speed are presented in tape format, but on the Head Up Display (Figure 4.9) it is in an analogue format. However, the compass information is presented in an analogue format on the Head Down Display compass, but on the Head Up Display it is in a tape format. The Primary Flight Display contains information that is crucial for the operation of the aircraft. It serves as a constant reference for pilots throughout the flight, therefore, presenting the same information in a different format on displays that the pilot is likely to switch between due to a malfunction of a display for example, can be mentally taxing.

4.4.5 Consistency in application of philosophy

Problems of inconsistency extend further to the way the automation design philosophy is intended and used throughout the cockpit, for example the use of philosophy for the Flight Director sign, on the Airbus 320's Primary Flight Display, which is '*Fly to*' or '*Fly towards*' philosophy. The Flight Director in this case indicates the required aircraft flight path to follow, i.e., 'fly to'. The figure (4.10) provides an example of Flight Director presentation on the Primary Flight Display. The Flight Path Vector shows the aircraft's current path and the Flight Director indicates the required flight path to be achieved. The pilot needs to fly aircraft towards the Flight Director to achieve commanded path (i.e. required path). Alternately the pilot can engage the Autopilot and the Autopilot will follow Flight Director.

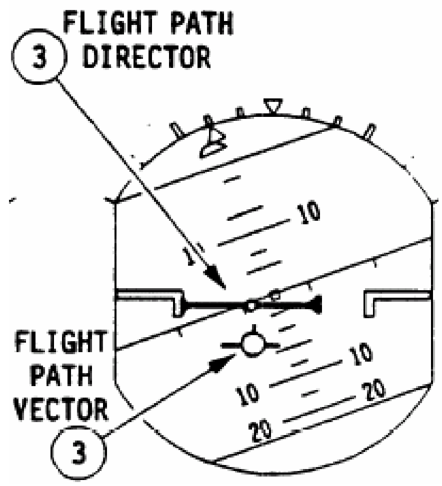


Figure 4.10: Airbus Flight Director (taken from (Ansett Australia, 1997) 1.22.30 p.3)

The directions by the Flight Director are given to the pilot for ease of flying precise trajectories, or for the Autopilot to follow. However, other signs on the same display do not follow the same philosophy, which can create confusion and incorrect actions on the part of the pilot. For example, the ‘bouncing ball’ sign on the speed tape indicates that the speed is too high and needs to be reduced. However, if the pilot would follow the ‘*Fly towards*’ philosophy, the pilot can interpret this sign as the need to increase speed instead of decreasing it. This action would give rise to further problems. The increase in speed would lead to breaking the Flight Envelop protection and would set off either alarms or even a mode reversion in some cases (problem 56, Appendix 2, Airbus 320).

The same, ‘*Fly Towards*’ philosophy, is applied to the Hercules’ Flight Director signs, but the philosophy is not followed on the same display throughout the features. For example, the Flight Path Indicator and the Glide Slope Deviation Indicator comply with the ‘*Fly Towards*’ philosophy, but the Speed Error Tape, Acceleration Cue and CAPS Distance tape do not comply with it. For example, if the Speed Error Tape is below the Climb/Dive marker it means the aircraft has deviated from the required speed. However, if the pilot interprets this as a ‘*Fly Towards*’ philosophy, the pilot would decrease speed even further (problem 14, Appendix 2, Hercules; also see problems 11, 12 and 13), making the opposite speed correction to the required.

In these examples the consistency in applying the same ‘Fly towards’ philosophy is beneficial, as the pilot is expected to respond to cues provided instantaneously and having cues providing contradicting information on the same display can setup the pilot for making a mistake.

4.4.6 Misplaced consistency

There are also cases of misplaced consistency. For example, there are actions performed by automation that are not consistent with the same actions executed by pilots. I have already presented an example problem earlier when discussing differences in strategies between automation and pilots. This causes the pilots’ confusion when automation does not perform an action as the pilot would, especially if the action has the same name, as the pilot traditionally calls it.

There are also cases of misplaced consistency when a different format of information is used for similar information. The Hercules C130J has two Primary Flight Displays, a Head Down Display and Head Up Display (see Figure 4.9), both of which carry the same type of information. The format of information presentation is different, partially because a Head Up Display is a monochrome display that allows the pilot to see through it to the outside. For this reason the information on the Head Up Display is presented in a minimalist fashion. However, this has made the presentation of the Airspeed Data and the Altitude Data indicator look similar on the same display (see Figure 4.9). It is presented as a circle of ten points with the reading in the middle. The problem occurs when the indications in the circles are the same, e.g. for a speed of 180 knots and a height of 180 feet. Pilots, especially new to the aircraft, tend to fail to differentiate which reading is decreasing, as reported by the flying instructor. If the pilots misread that the speed is reducing instead of altitude the pilot would think the aircraft is about to stall. The pilot would respond incorrectly and put the aircraft into an incorrect attitude very close to the ground, at which point there is no margin for correcting the error.

Caution needs to be exercised in using the consistency principle as guidance in the design of information presentation. Every case needs to be examined in both, helpful and misleading, instances, specifically to assess whether, how and under which conditions it will help or mislead the operator in information presentation before it is applied.

4.5 Concerns that did not fit in the existing taxonomy

During the classification of problems there was a cluster of concerns that did not fit into the current taxonomy, as on the surface these concerns do not appear to be problems. These can be categorised as problems of a lesser degree that are not obvious, but can be improved on. This category at first sight can be seen as weakness in pilots' ability to find and to associate information and to memorise and recall it at the appropriate time. Not all of these problems are listed in the problem table (Appendix 2). I will take a few examples of these problems to show what they are and what they have in common.

4.5.1 Semantic problems

There were less obvious problems of a semantic nature and these would not appear to be a problem if the pilot would memorise by heart the meaning behind each symbol or word. However, if the pilot forgets the symbol's meaning and would think of a possible logic behind each symbol, to establish what it means, errors would occur. For example, the Non Directional Beacon symbol is represented as a triangle. Although this beacon does not provide the direction, the triangle can be interpreted as an arrow and the symbol can be thought of as a Directional Beacon. However, the Directional Beacon can provide a direction, but it is represented in a circle, and it is difficult to ascertain direction from a circular symbol (problem 63, Appendix 2, Airbus 320).

There is a similar problem related to the semantic interpretation of signs on the Hercules Head Up Display. The Pitch recovery symbol, called the 'Chevron pairs', looks like this ^^ and indicates that the nose is high. This again, as discussed earlier, contradicts the '*Fly towards*' philosophy featured on the same display, which can be interpreted as an indication to 'recover in this direction' by following the arrows. A problematic issue with 'Chevron pairs' is that there is the same symbol, but as a singular Chevron ^ that indicates that the nose is low and shows the direction in this case that the pilot should recover the aircraft. If the pilot misinterprets one of these chevrons, the aircraft would be recovered in the wrong direction, both of which would result in the unusual attitude. (problem 1, Appendix 2 Hercules).

Therefore, the meaning behind symbols or icons can be ambiguous due to variety of factors, for instance user skills (McDougall & Curry, 2004). Meaning behind words can also be misinterpreted. Such instances arise as mode annunciations are shown as acronyms or shortened words. This is open to pilot misinterpretation, such as in problem 47 (problem 47, Appendix 2 Boeing). Consider a case, during a take off run the Autothrottle cannot be changed until the aircraft reaches 80 knots per hour, the Autothrottle then goes into HOLD mode, which is annunciated on the Primary Flight Display. At this point the Autothrottle can be altered, however, the word 'HOLD' may be misinterpreted as the Autothrottle is 'on hold' and cannot be altered. The pilot who reviewed the problem and concern table (see Appendix 2) explains how he remembered the correct meaning behind this mode annunciation:

#47: “… a reasonable interpretation of the HOLD annunciation. It merely means the throttle servos have "let go" and the throttles will remain where they are with no action needed by the pilot.”

From the pilot’s interpretation, above, it is unclear, does this word ‘HOLD’ refer to what the automation is doing or what the pilots should be doing? Mode annunciation per se has to explain the automation’s action, but from this pilot’s explanation, the mode is telling the pilot what to do. This notion returns to the previously discussed problem of consistency, only in this case it is consistency with respect to the assignment of names to mode annunciations and their double meaning.

4.5.2 Poor location of related information and function (environment related)

Poor location of related information and function refers to situations where, the locations of important related information are located apart from each other and are not associated. For example, on the Hercules Head Up Display the barometric pressure information is remote from altitude information, even though the altitude reading may be correct, the barometric pressure setting may be incorrect meaning the altitude reading will be incorrect. Related information that is positioned apart from each other may be not cross-referenced. Nearly half of the pilots surveyed reported such an incident, when the pilot set the wrong barometric pressure. The survey of forty-six pilots responded that 45.7% of themselves or 45.7% saw another pilot ‘had an incorrect barometric air pressure set’ (Demagalski, J. *et al* 2002).

The DME (Distance Measuring Equipment) information is similarly remote from other related navigational data (problem 32, Appendix 2, Hercules). If the pilot reads the navigation information correctly, but from the wrong source, the information is of no use.

4.5.3 Poor location of related information and function (behaviour related)

The button that activates automation behaviour is located apart from other automation selection associated with the same behaviour. The Mode Control Panel layout has a

FLCH (Flight Level Change mode) button located under the IAS (Indicated Air Speed mode) button, which are not related. In fact, the associating and activating button, the ALT selection knob is located apart from each other (problem 35, Appendix 2, Boeing 777).

4.5.4 The relationship that limit the behaviour are not represented:

The pilot often does not know, unless he/she has memorised, all the conditions, that modes will activate under, and also can’t recall all modes that will limit the aircraft’s behaviour. For example, if the pilot uses the ALT* (i.e., altitude capture mode) in descent, the aircraft will become locked until the altitude is captured. The mode cannot be changed until the aircraft exits ALT* mode (problem 86, Appendix 2, Airbus 320).

4.5.5 Tolerance boundaries of the automation operation are not presented:

Automation has operational boundaries that are pre-programmed into the system called the flight envelope. Some of these boundaries are important for pilots to know. For example, during climb the selected NAV (i.e., Navigation) or ALT (i.e., Altitude) mode may not capture course (NAV) or altitude (ALT) respectively, if there is a deviation. The altitude will only be captured within 10% of the rate of climb and the course will be captured only within 5% of the target course. This information is not announced to the pilot, and the pilot may not be aware why the automation did not accomplish the operation (problem 15, Appendix 2, Hercules).

4.5.6 Automation dependencies are not represented to the pilot

Automation design is complex and comprises many interactions between the various automation functions in various combinations, which again the pilot has to know and recall at the appropriate time to engage automation and to avoid any surprises. For example, ATHR (i.e., Autothrottle) will not engage below 100 feet, if a Flight Director and an Autopilot is disengaged (problem 90, Appendix 2, Airbus 320).

4.5.7 Understanding automation intentions

There are a multitude of problems that can fit under several categories in the Alternative Taxonomy, but these are the most applicable in helping pilots to answer questions, such as, ‘What’s it (automation) doing now?’ This is often asked during line operation. The Airbus philosophy is based on a strategy to help pilots fly the plane effectively, provided they always can answer the following question, ‘*What do I want the aircraft to fly now? What do I want the aircraft to fly next?’*. If the pilot can answer these questions it will help pilots fly an aircraft safely and follow the most fundamental rule, ‘a pilot should be always ahead of the aircraft’.

These problems have been discussed in part in the previous categories mentioned in this section and in details in the sections, ‘behaviour of automation goes on unnoticed’, ‘pilots unknowingly affect aircraft behaviour’. Poor interfaces and displays contribute to these problems, but are not the only cause of pilots misunderstanding of automations intention. Already mentioned ‘automation surprise’ can also fall under this category.

Pilots' misunderstanding of automation intention appears to be a result of several factors, such as, a missing piece of information that influences or contributes to the automation behaviour; not understanding the logic behind automations behaviour; or pilots' assumptions that an action was preformed and completed, but it did not, or did not happen in an excepted manner, such as in the Strasbourg accident. Another related example, as reported in the preliminary finding of the newly developing human factors certification criteria (Demagalski, J, et al 2000), is where the pilot assumed that the mode was activated, but in fact, 34.8% of pilots 'entered a heading on the Flight Control Unit and failed to active it at the appropriate time'.

Pilots' misunderstanding of the automation's apparent intentions can be caused by, and result in, mode reversion, which at length is discussed in this chapter in various categories. For example, 15.2% of pilots themselves or 17.4 % of pilots know of other pilots who 'entered the wrong altitude on the Flight Control Unit and activate it' (Demagalski, J, et al 2000). This action can lead to an altitude mode reversion, discussed earlier (i.e., cause aircraft to ignore the pilot's entry and keep descending or revert to climb), which in turn causes the 'automation surprise' phenomenon.

All of the above problems were observed during training and line operation and although the pilots tended to memorise how to avoid these problems, they were still often caught by surprise by them.

From my training and observations, it appears at times pilots were being trained to avoid making mistakes and learn the instructors or colleagues' tricks on how to avoid automation traps, instead of learning of how to operate an automated aircraft. Partly, as it transpired through the course of research, it is because the philosophy, although having a great foundation behind it, is not followed throughout in the cockpit design. The very things that the automation is good at and can be helpful at, such as, retaining, calculating, analysing information and highlighting when information is needed, is in fact not used to the full extent.

4.6 Discussion

4.6.1 What is the problem in the cockpit interfaces?

At this point it is appropriate to ask the question: how can it be so easy and natural to pick up basic flying skills, but it be so challenging to learn, operate and understand an automated aircraft? The fundamentals of flight have not changed since we first started flying and the basic rules of flying, i.e., assessing the 'health' of the aircraft, navigating according to the flight plan and communicating with the Air Traffic Control are still the same. The only new step in the operation of an automated aircraft is monitoring. Automation was designed to offload work from the pilot, by giving the automation the tasks that we as humans are not efficient at, such as repetitive tasks, leaving pilots with higher order decision making and problem solving (Billings, 1991).

The pilot needs to constantly monitor the system, retrieve the required information from the system, recalling the conditions under which the automation would or would not work. Although the automation is intended to offload pilots workload, it is arguable that the time pilots spend on contending with automation, cancels out the time pilots gain by having the automation at their disposal.

During my training, through observation of pilots in training and in line operations the major contributor to problems pilots have with automation appeared to be their poor understanding of automation systems. Pilots were observed to struggle to understand how to operate an automated aircraft, more often than not making mistakes, and were surprised by the automations behaviour. Pilots found it difficult to learn and to follow the philosophy applied in the design of the displays, and the logic that the aircraft's automation followed during the operation.

It transpired that the problems of pilots' understanding the automation, observed during training, continued through to line operation. Pilots were gaining an understanding of the automation philosophy through training by means of training aids. Their further understanding of automation was gained during operation, where pilots were using the automation systems through the variety of interfaces. Pilots often exchanged tricks and applied workarounds to successfully operate the aircraft. However, neither training, exchange of tricks, nor line operation actually increased their understanding of many aspects of the automation system. Pilots were still confused about automation operational logic and struggle to understand its philosophy (Figure 4.11).

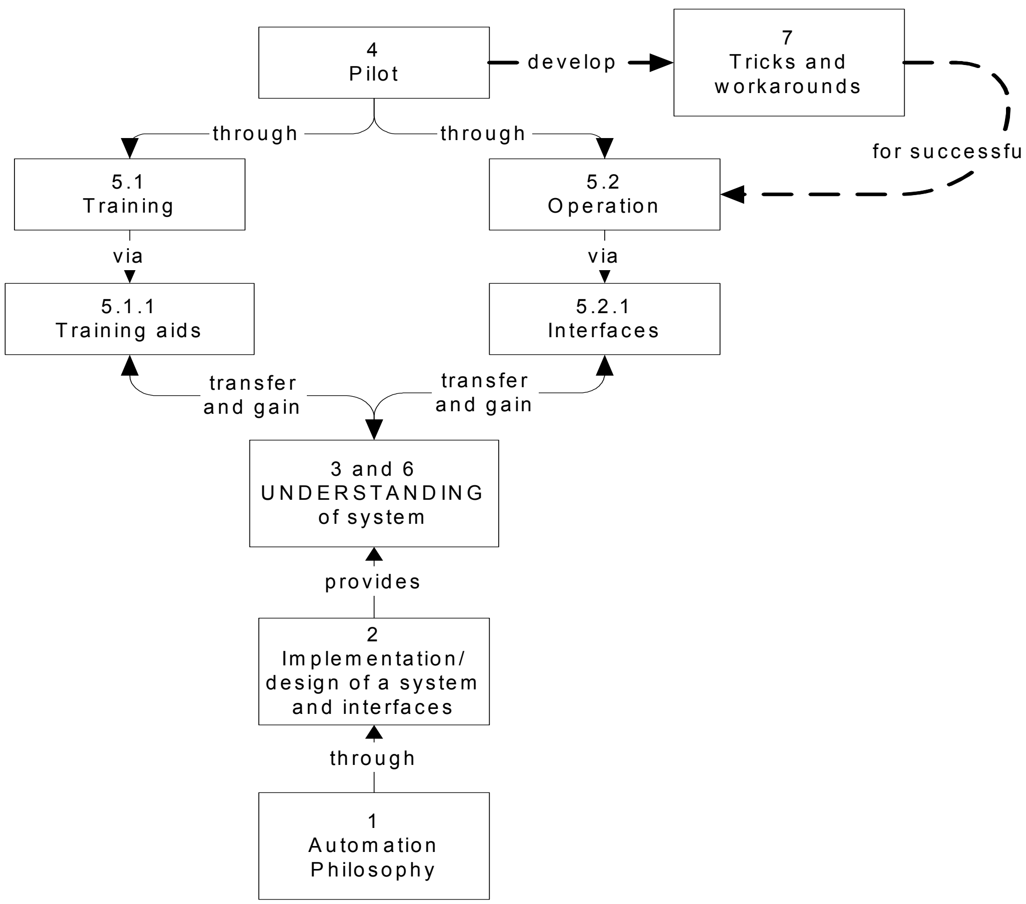


Figure 4.11: What is the problem?

One part of the problem in pilots' understanding of the philosophy is the implementation of it inconsistently throughout the design of the system.

As I discussed in the example problems in this chapter, pilots have numerous opportunities to misinterpret the automation mode annunciation, to select the wrong mode of operation, to loose track of automation actions after mode reversions, and to miss crucial parts of information that in turn effect how the automation responds. Pilots had to largely rely on memory to recall the 'if conditions' when interacting with the automation system and were surprised when the automation did not respond as expected.

Automation dependencies are not represented to the pilot

Automation design is complex and assumes interactions between automated subsystems in various combinations, which again pilots' have to remember and recall at the appropriate time to engage automation and to avoid any surprises. For example, ATHR (i.e., Autothrottle) will not engage below 100 feet, if a Flight Director and an Autopilot is disengaged.

To validate the example of problems and concerns in the Appendix 2 that are discussed in this chapter the table (see Appendix 2 for table of problems and concerns) was given to experienced pilots on each aircraft type to be reviewed. One pilot's response to a problem (problem 90, Appendix 2, Airbus 320) described in the section 'Automation dependencies are not represented to the pilot', related to relying on pilots memory to operate the automation, was:

"#90: Yes, that is true with the following caveats: Although I can not find this in my airline's AFM (i.e. flight manual), I believe the following is correct: Below 100 ft AGL, SRS ("speed on elevator") is only available if at least one F/D is ON; however, ATHR is available below 100 ft if in "speed on throttle" mode as is normal with G/S engaged during an instrument approach;"

This is a good example of a concern that questions the design philosophy. Every rule and condition that the pilot has to remember has an exception that applies to this specific rule and condition. From reviewing the manuals, it appears that there are many rules and exceptions and it becomes evident that 'a rule' applies to only one situation. This is demanding on a pilot's memory and is a skill that, compared to automation, humans are poor at. This cognitive human ability should not be challenged by automation, like it is now, but instead supported.

4.6.2 Why is there a problem in design of interfaces?

Levels of automation have increased in the cockpit, but the information presentation has not significantly progressed in several areas. The basic flying instruments have been the same 'T configuration'[2] for the last century only. Analogue displays have been changed to digital so, information is now presented in an alphanumerical form. Checklists

[2] "The basic T-configuration is defined as an arrangement where the airspeed and altitude data are centered, respectively, directly to the left and right of the attitude data, with the direction data located directly below the attitude data." (p. 17, FAA, 1999)

became electronic, but still are in a text format. Boeing added a new feature to checklists, where the completed actions are automatically checked. The only really new displays is a Navigational display with a map, weather and terrain information, but then it is very similar to conventions from a paper version used for over a century.

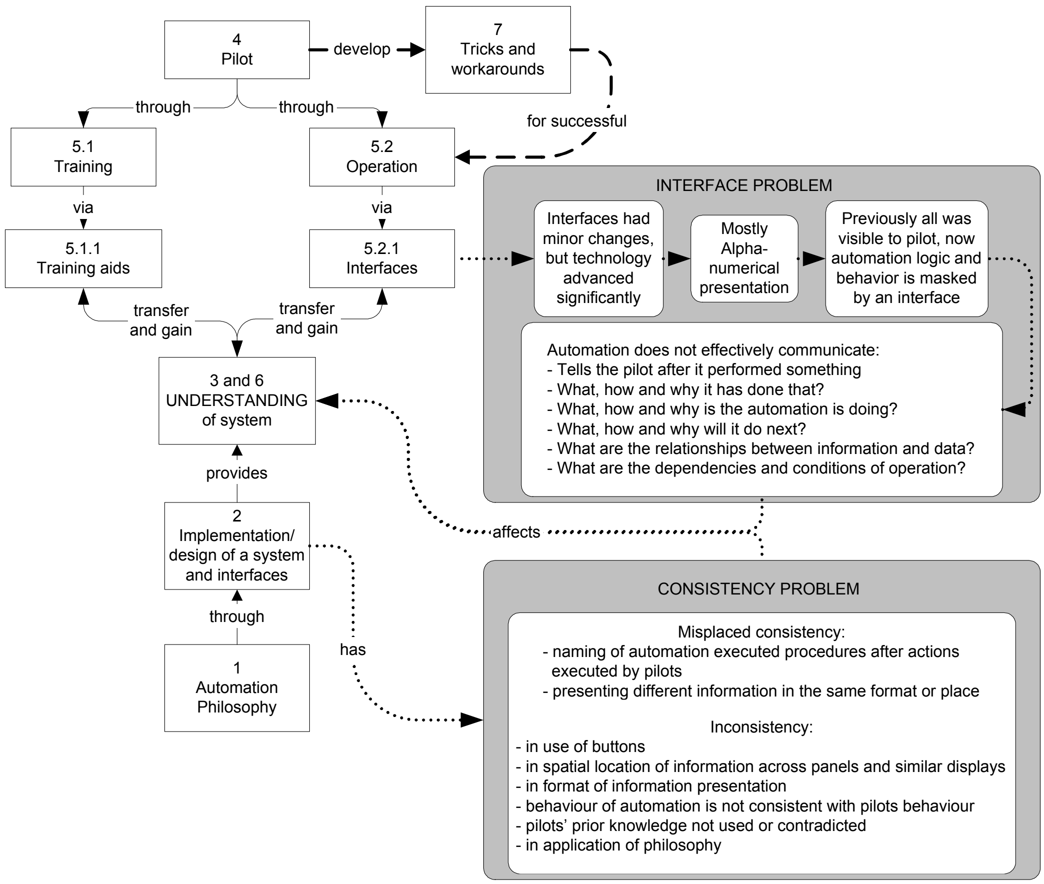


Figure 4.12: Why is there a problem?

The information that the pilots need to have about the automation, is poorly, or not presented at all (Figure 4.12: Why is there a problem? see Problem areas). Airbus philosophy states that the pilot needs to understand the system, in order to effectively monitor its progress. Therefore, pilots need to know the answer to two questions: *What do I want the aircraft to fly now? Where do I want the aircraft to fly next?"* (Tarnowski, 1999). Yet, this information is not readily available to the pilot, the automation does not help consolidate or present this type of information. Apart from the Navigational Display, where the course of the aircraft is presented, but there is little information about the automation behaviour.

A contributor to the pilots' poor understanding of the system is a 'consistency problem' (Figure 4.12). Throughout the cockpit there is a poor or misplaced consistency in the implementation of the philosophy behind automation and the operational logic. The problems in implementation of consistency in design stretch from the information presentation, to the use of buttons, to inconsistencies in the application of philosophy in design of individual features.

This problem of maintaining consistency throughout the implementation of the cockpit design feeds into the manuals and training aids that in turn require pages and pages of explanations justifying these inconsistencies which results in all the 'if conditions' that pilots need to memorise. This makes training cognitively demanding and does not improve pilots' understanding of the system during line operation.

As a consequence, both pilots and instructors have come up with coping strategies to help pilots memorise all possible 'if conditions' and automation procedures. They invented workarounds where they did not understand the system's behaviour and performed the action in a more familiar and convenient manner.

One type of problem in pilots poor understanding that lead to several accidents, was observed during the conversion training, and in line operation and also reproduced during experiments (Sarted and Wood, 1994) and consequently is of special concern. It is when the onset of the problem is either masked by automation, or not evident from the displays. The pilots are consequently blind to problems and are unaware of the automation's intentions, or cannot deduce the automation's intentions from the available information.

In majority of instances the information that will lead to understanding the intention of automation is available somewhere, but in text format manuals or from a search through the Flight Management Systems, however this is generally not an option in a quickly deteriorating situation. A conventional scan of instruments will also not help deducing this information, because the information has to be read and processed. The alphanumerical presentation of modes makes it difficult for pilots to construe the automation's intention out of the hundreds of possible combinations of 'if conditions'.

From accident reports it can be seen that flights that lead to accidents were, where pilots misunderstood automation's behaviour in one form (Bangalore, one Flight Director left switched on) or another (Strasbourg, V/S entry incorrect). However, the way automation behaviour is presented to pilots has not changed much since these accidents apart, for example, from adding a couple of digits to a V/S window after Strasbourg accident. The problems begin when the behaviour of automation goes on unnoticed until it is too late to change it. Generally, the problem can be avoided provided the information is available and the pilot can see the information in the first place, such as seeing the effects of the actions they are performing or selecting a mode of behaviour to be performed by automation.

All the examples that were discussed in the section on pilots training have common problems, that the philosophy, the logic and the rules are not visible to pilots. They are hard to remember, because they do not reflect any common operational rules the pilots would ordinarily follow, or are taught to follow early on in their flight training. Additionally, none of this crucial information, that pilots need to know at various stages of flight, is reflected on displays.

4.6.3 Classification can helps understanding of the problem

As discussed in the 'Classification of problems and concerns' section of this chapter, it was found that the current taxonomy could not fit some categories of problems and concerns, such as those that require a semantic and information relationship category for example. Existing taxonomy was helpful in showing the scope of the problems observed in this research, but not helpful in its classification for the purpose of identifying and helping to solve the root of the problems in an automated cockpit. It is also not designed to trace and identify the links between problems, which is crucial to resolving them.

Several trends in problems were discussed that are helpful in identifying leads to roots of problems. An alternative view on the problems in the cockpit is suggested that will help to classify problems according the root of the problems.

There are three possible categories of information that pilots did not follow or understand, (1) physical form (appearance i.e., configuration of the aircraft), (2) behavioural (i.e., combination of modes leads to a specific behaviour) and (3) environmental (i.e., navigation, weather related problems).

Categories of problem information	Description
PHYSICAL FORM	Information related to physical appearance i.e., configuration of the aircraft
BEHAVIOURAL	Information related to behaviour, i.e., combination of modes that leads to a specific behaviour
ENVIROMENTAL	Information related to navigation, weather and terrain

Table 4.1: Categories of problem information

There are also three levels to the problems pilots have in understanding these type of information, (a) perceptual (i.e., straight representation on the display, for example position of flaps or amount of fuel left or available), (b) semantic (i.e., the form of representation that is open to interpretation, such as an example of Directional and Non-directional beacon representation) and (c) contextual (i.e., surrounding conditions that would determine the situation; context would determine conditions of operation, for example 'if conditions' or nature of the situation) (see Table 4.2).

Levels of understanding	Description
PERCEPTUAL	Relate to presentation of information
SEMANTIC	Relate to meaning behind the representation
CONTEXT	Relate to interpretation of information under various conditions

Table 4.2: Levels of understanding

All of the problems in understanding automation, whether perceptual, semantic or contextual in nature were related to information about either the state of the aircraft, the behaviour it is exhibiting, or about to be exhibited, under specific conditions in the surrounding environment.

Pilots constantly connect information, draw parallels and connections between dependent pieces of information, but this is not reflected on the display, apart from the Navigation Display, where the route is presented with some related information, such as altitude restrictions. Disconnected information effects how pilots interpret information.

Therefore, after the problems are classified into three categories and three levels of understanding, there is a need to establish if there are possible relationships and links among the pieces of information that are dependent on each other, such as for example, altitude information being dependent on the altitude pressure. The links in information are later determined through a study discussed in the next chapter five. The classification of problems can help resolve design problems as will be shown in chapter seven.

4.6.4 The problem is deeper than it appears

For purely the presentation of information upon the interfaces to be the cause of the problems that pilots have with automation this would assume that the automation philosophy is correct and has no flaws. It follows then that the root of the problem lies in the implementation stage of design where the system and the interfaces are created. However, through the training and observations discussed in this chapter, it was established that the pilots had problems not only in understanding the information presented on the interfaces, but also that the automation used different strategies to pilots. Pilots misunderstood, and were surprised by, the automation's behaviour. It was evident that automation responded differently and performed sequences of actions not in the way pilots expected. This leads me to reconsider whether the assumptions behind the design of automation philosophy is partially responsible for problems that pilots have with automation.

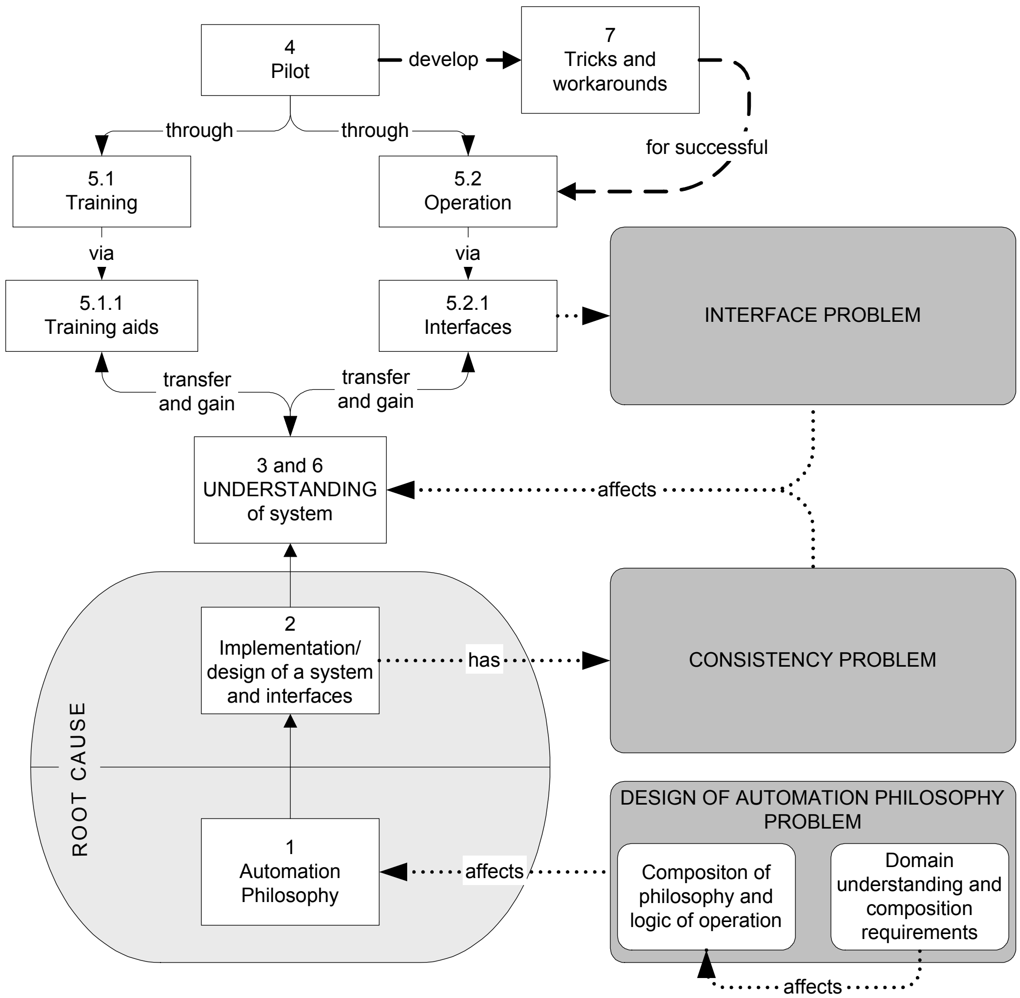


Figure 4.13: Where is there a problem?

From the figure 4.13 it can be seen that the root cause of the problems lies in both parts, the assumptions behind automation philosophy and the implementation stage of design. The philosophy of automation needs to reconsidered. It appears to have major differences between how pilots actually think of aircraft operation and the way automation is designed to operate the aircraft.

Poor conceptualisation of automation philosophy has a direct affect on pilots understanding of the system, because the design and the implementation of the system and the interfaces would be based on the philosophy that does not reflect pilots' understanding of aircraft operation. It appears that the automation philosophy does not accurately reflect pilots operational experience, where pilots use strategies, basic operational rules and any natural means of sensing and reading information.

4.6.5 What may be done about it and how?

The problem of pilots' poor understanding of automation should be attacked at the root cause, at the level of design of automation philosophy and the operational logic (Figure 4.13 above). There is a need to improve the understanding of the domain and help conceptualise the philosophy of automation. We (i.e., the designers with Human Factors, Human Computer Interaction and Cognitive-Engineering background) need to go to the source and learn from observing how pilots operate an aircraft. During the last century pilots have gained experience and developed skills in operating aircraft. Through observation and analysis of collected data understanding of the domain can be improved that will help to acquire a set of requirements that in turn will help improve the automation philosophy.

The areas of concern and difference between pilots and the automation have already been established. The next step would be to explore and gain a deeper understanding of how pilots view the operation of the aircraft. This would help to form an improved model of future automation philosophy.

Areas of concern: (where pilots have problems)	**Areas of investigation: (where pilots need support)**
Differences in strategies	Identify strategies and techniques pilots use
Differences in operational logic	Establish pilots’ operational logic
Fundamental rules are not supported	Identify rules pilots use
Poor presentation of information	Identify information pilots use during operation
Poor understanding of information, relationships, links, dependencies	Identify relationships, links, dependencies in information

Table 14.3: Concerns and areas of investigation

The table (14.3) above summarises, in the left column the areas where pilots have problems, and the right column areas where pilots need support. This table indicates directions for further investigation. From observations of line operations and conversion training, it became evident that pilots build on and draw on prior knowledge and experience. There is a need to systematically observe and learn about pilot experience if pilots are to help in informing the design at the root cause level (Figure 4.13)

The pilot and the cockpit are equipped with abundant opportunities to inform design in a form sympathetic to pilots’ fundamental rules, strategies operational logic and the various types of information they need. Designers can explore how pilots use a conventional cockpit and the automated cockpit. The designers can take advantages of both types of technologies and use it to pilots’ operational advantage. For example, successful strategies that pilots use in operation of automated and conventional aircraft need to be utilised. The types of instruments pilots embrace or avoid using in the automated cockpits need to be known and the new instruments assigned accordingly.

In the systematic empirical study there is a need to address the points listed in the table of concerns and areas of investigations (see table 14.3). These pieces of information that would help develop and to form improved automation philosophy, that will account for pilots’ strategies and rules, at the level of the root cause of problems pilots have with automation. During the design and system/interface implementation stage there is a need to take into account the problem of consistency and answer the questions that pilots have regarding automation (Figure 4.13). The questions have to be answered in terms of three information problem categories (i.e., physical form, behavioural and environmental) and they should be clear to pilots at three Levels of Understanding (i.e., perceptual, semantic and contextual)

Currently, new ways of piloting have been imposed on pilots as have new ways of using information in flight, maybe there is not a need to invent a new way to present information here but a need to go back to the basics and see how pilots collect and use information in a 'conventional' flight and with this use new technology to offer the presentation of information to pilots based on what they 'require'. There is a need to learn how they collide and refer to information they know or would like to know about the aircraft systems and its' behaviour.

4.7 Conclusion

In this chapter in preparation for an empirical study I learned about the steps trainee pilots take to become a pilots; how pilots form basic knowledge, gain experience as a line operationing pilots in commercial airlines. Meanwhile, I have been able to learn the terminology, such as commonly used abbreviations and professional jargon that are typical to the aerospace domain.

I outlined the difficulties pilots face when they are transitioning from a non-automated to an automated cockpit. I showed that automation and pilots have different strategies in operation of the aircraft. I discussed the types of problems pilots have in dealing with automated cockpit.

I classified the problems and concerns in the established Alternative Taxonomy (Funk and Lyall, 1998) that I experienced while conducting training myself, observing pilots in training, during line operation in the current automated cockpits, plus further problems uncovered from manuals were discussed.

I identified several levels of problems that lead to pilots' poor understanding and suggest steps to resolve these problems in the automated cockpit. I suggest questions to be answered in the systematic empirical study which is described in the next chapter.

The problems that pilots have with automation appear not to originate in training or arise because of poor operational practice, or because pilots have poor memories or poor use of displays. The problems originate from fundamental assumptions at the beginning of the design on which the automation philosophy and design of systems and interfaces is based.

By comparison, the training and operation of the non-automated (i.e., conventional) cockpit is easy and intuitive, while in the automated cockpit it is challenging to pilots. Pilots during regular flights use 'tricks' and workarounds to fly an automated aircraft and more often than not are surprised by automation's actions and outcomes that are different to pilots' intentions.

Basic flying skills are natural, however flying an automated aircraft, that is supposed to make pilots' work easier, is in fact challenging. The proposal is to observe pilots at work and to learn from them how to support their work in a more effective, natural and efficient way; and to learn to support their strategies and rules and to answer the questions pilots constantly ask about the automation, while operating an automated aircraft through the design of future interfaces.

Chapter 5: The Empirical Study

5.1 INTRODUCTION

From the description of ‘pilot experience’ in chapter four, it appeared that pilots have difficulties transferring knowledge used previously in non-automated aircraft to automated aircraft. Observation of pilots, both in training and during operation on-line, showed that pilots attempt to use the same strategies, and apply the same rules that they used in non-automated aircraft in the automated aircraft. As a result more often than not pilots are surprised by automation response and behaviour (Sarter and Woods, 1997).

Further investigation of a ‘pilot experience’ leads to the view that the user-interface is not a primary cause of pilots misunderstanding of the system. As a result of these observations, there is an assumption that the user-interface is not the root problem in pilots misunderstanding of operation of the automated aircraft. The root cause of pilots misunderstanding lays in the basic structure and implementation in the automation ‘philosophy’ during design. It appears pilots, and automation, have major differences in how they operate the aircraft.

This chapter describes an empirical study that systematically discovers the information, structure of information and strategies that pilots use to understand and operate the aircraft. The aim is for these elements to be the basis of a design philosophy for automated aircraft, and that displays should also be developed to support and comply with pilots’ strategies and rules of aircraft operation.

It was observed in an observation and participatory study (chapter 4) that pilots used various strategies when collecting and using information in the automated and non-automated cockpits. Consequently, it was decided to study pilots operating the aircraft both using automation to the full degree and not using automation at all. Both settings were set up on the same aircraft, flying the same route. The only difference was the extent of automation used. This detailed study allowed the observation of: how pilots collect and use information; the strategies pilots use when they do not have access to required information; the use of well-ingrained flying experience (which is argued later in chapters six and seven should be the basis of design).

A cue-recall-debrief method was chosen as the basis for this enquiry. The method was modified after the preliminary study (chapter 3) to suit the purpose of this empirical study, to systematically investigate the information, structure of information, and strategies that pilots use to understand and operate the aircraft. The suitability of method is discussed and an evolutionary (‘evolutionary’ because the investigation of dynamic environment requires a dynamic and adaptable analysis technique) analysis techniques described here in details as it developed.

Finally, the results of the analysis are presented in steps to help the reader follow the researcher’s process of uncovering the information, the information structures and strategies that pilots use. The chapter concludes by revealing the information structures and the strategies that pilots use in everyday operation, focussing on the pieces of information that pilots generate themselves, and identify on the display and outside in the environment, to operated the aircraft efficiently.

5.2 METHOD

This study used a knowledge elicitation method, called cued-recall-debrief, inspired by the method developed by Omodei (Omodei 1997). This original method was tested and specifically modified during a preliminary study on pilots, which is summarised in Chapter three. This method was chosen as it highlights how experts retrieve information in complex, time-critical and dynamic environments. The main advantages of this method are:

a. it does not disturb pilot's continuous operation of the aircraft;
b. it allows pilots to relive the flight during a debrief session;
c. it cues pilots to recall inner processes at any point of flight;
d. it allows the researcher to ask all the questions required for the study without interrupting pilots operational environment.

The advantages and modifications to this method have been described in Chapter three, however, for a shorter summary see Figure 5.1 below.

This knowledge elicitation method, complemented with a naturally evolved analysis, (also described in Chapter three), allows the capture of pilot's natural thought processes and tracks pilot's needs for certain cues and information vital during all stages of flight. This whole method was modified to a one-stage-cue-recall-debrief, which is suitable for the purpose of this study and it shortens the debrief time.

The questions asked during the debrief were adjusted to be cued on 'flight events', because pilots' mostly assess a situation by flight events and the information they assess does not change much apart from when a particular stage is entered, i.e. climb, cruise, descent, finals. This was confirmed during a preliminary study and through observations, reported in Chapter four. Details of questions asked are given later in this chapter in the section on 'task and procedure' and a form with the questions given to pilots is provided in Appendix 3.

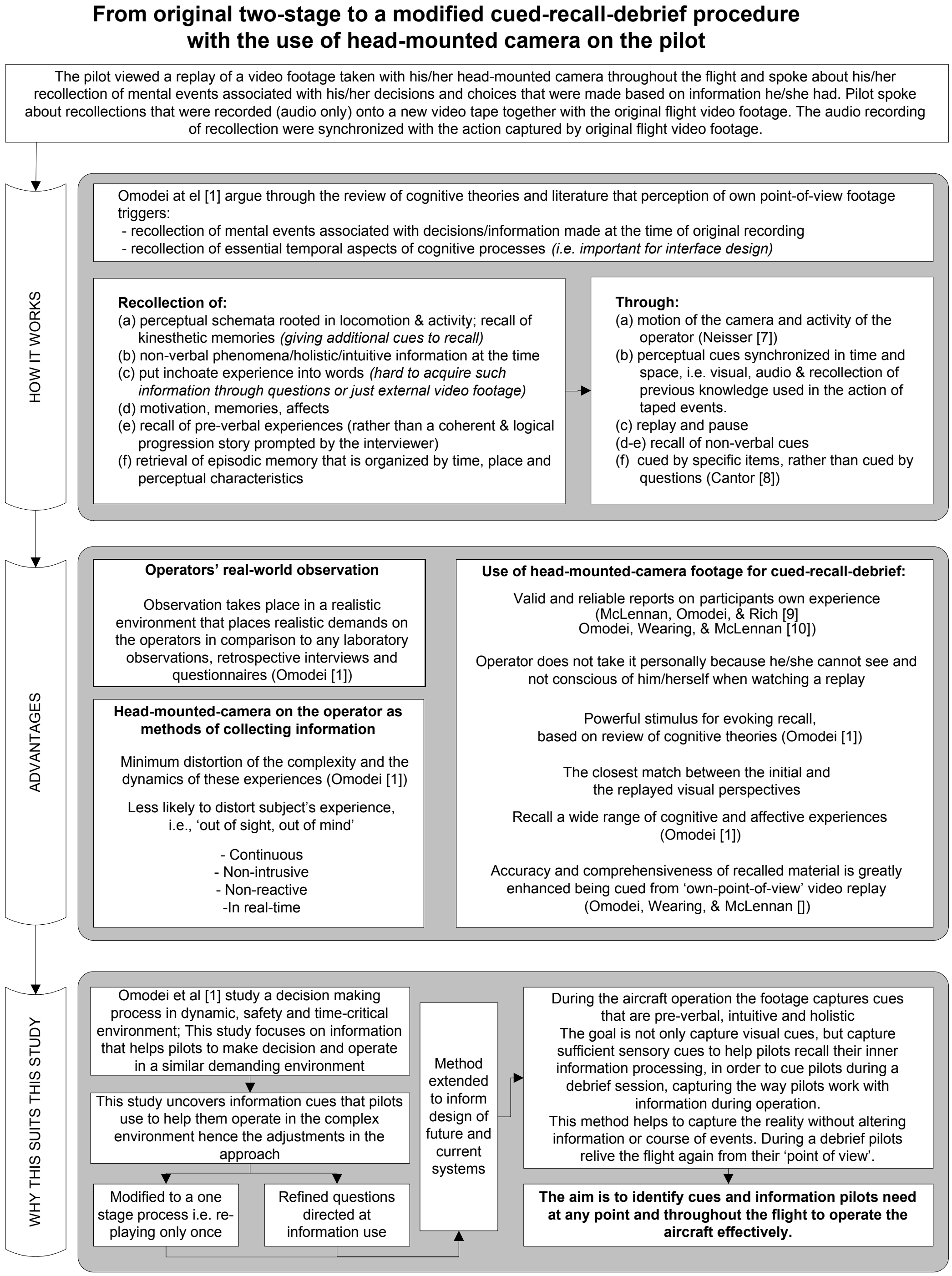


Figure 5.1: Rationale for the use of a modified cued-recall debrief method

5.2.1 Experimental Scenario:

The participant pilots flew a simulated full motion regular flight from Sydney to Richmond, which lasted between 15 to 20 minutes. Pilots were briefed to take off from the assigned runway at Richmond Air Force Base, to climb to 5000 feet, and to navigate to an assigned runway in a busy Sydney International Airport. Halfway through the flight the Air Traffic Control was to switch a runway. Pilots flew one flight with full use of automation and the second flight with the minimum possible use of automation.

The flights for all pilots were identical. There were three conditions repeated on all flights to assist in collecting the required data.

First, half way through the flight a runway change in Sydney was announced by Air Traffic Control. This aimed to increase pilot's workload before and during a landing phase. This condition helped to create a situation where pilots had to deal with new information and had to make changes to cockpit set up accordingly.

The second condition included the simulation of other air traffic, displayed and communicated through the radio. This was done to add realism to the flight.

The third condition related to the weather. A cloud base between 1500 to 25000 feet was simulated to prevent pilots from seeing the ground at the top of climb. Consequently, pilots' had to rely on instruments in the cockpits and only during take-off, approach and landing had good visual conditions. This allowed the observation of pilots switching between instrument and visual operation of the aircraft. All other weather parameters were identical for all flights, such as head and cross wind, air pressure and temperature.

5.2.2 Participants:

The study involved observation of two crews (two pilots in each crew) in a C-130J simulator. All participants were male military pilots. Pilots had on average 1600 (SD = 663) total flying hours and had extensive experience (on average 825 (SD = 415) flying hours) on the Electronic Flight Instrument System, which is another way of referring to a cockpit equipped with automation. All pilots had recently transitioned to a new generation Hercules C-130 a J model, which had recently been introduced to the fleet of the Royal Australian Air Force. Pilots also had similar previous flying experience on both types of aircraft, the C130J with, and the C130 without cockpit automation. Further details are given in Table 5.1 below.

Pilot		**Flying hours**		**Type of aircraft flown**
		Total	**Electronic Flight Instrument System**	
Crew A	1	1700	400	PC9; C-130 model E and J
	2	1100	800	PC9; MACCH1; C-130 model E, H and J
Crew B	3	2500	1500	PC9; F900; C-130 model E, H and J
	4	1100	600	PC9; C-130 model E, H and J
Mean of flying hours		**1600**	**825**	**All pilots had similar flying experience**

Table 5.1: Flying experience

A sample of observations were selected, from the participant population, which included both junior and senior personnel, i.e., two captains and two first-officers. The researcher made no discrimination, all pilots that were available participated in the study.

5.2.3 Equipment:

This study took place in three settings, a general briefing room, a full motion level five Hercules C130-J flight simulator and the debriefing room. The debriefing room required separate set up and equipment.

5.2.3.1 Briefing room

The briefing room had a simple set up of four chairs, an oval table and the briefing board. This is where all regular flight briefings take place and was chosen (Figure 5.2) in attempt to make the study as similar to regular operation as possible.

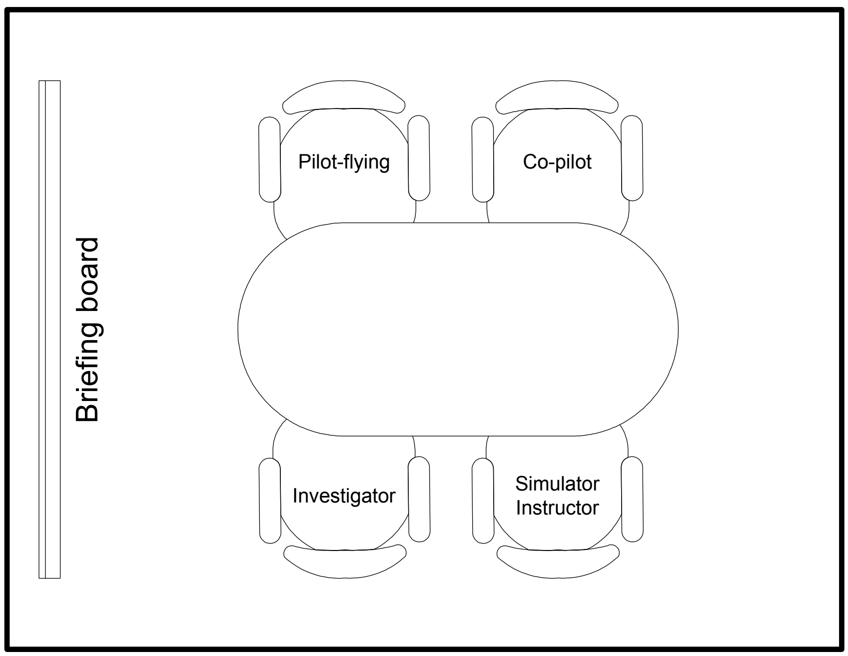


Figure 5.2: Briefing room setup

5.2.3.2 Full flight simulator

All flights took place in a full motion level five (i.e., closest to reality, the highest level of simulation) Hercules C130-J flight simulator. The simulator set-up was not altered in any way, with the exception of a head-camera on the head of a Pilot-flying. The researcher and the instructor were situated at the back of the simulator. The researcher monitored the progress of flight in accordance with the study's conditions. The instructor ran the simulator manipulating weather conditions, simulating Air Traffic Control and simulating communication of other air traffic on the same radio frequencies. The setup of the simulator is illustrated in Figure 5.3, below.

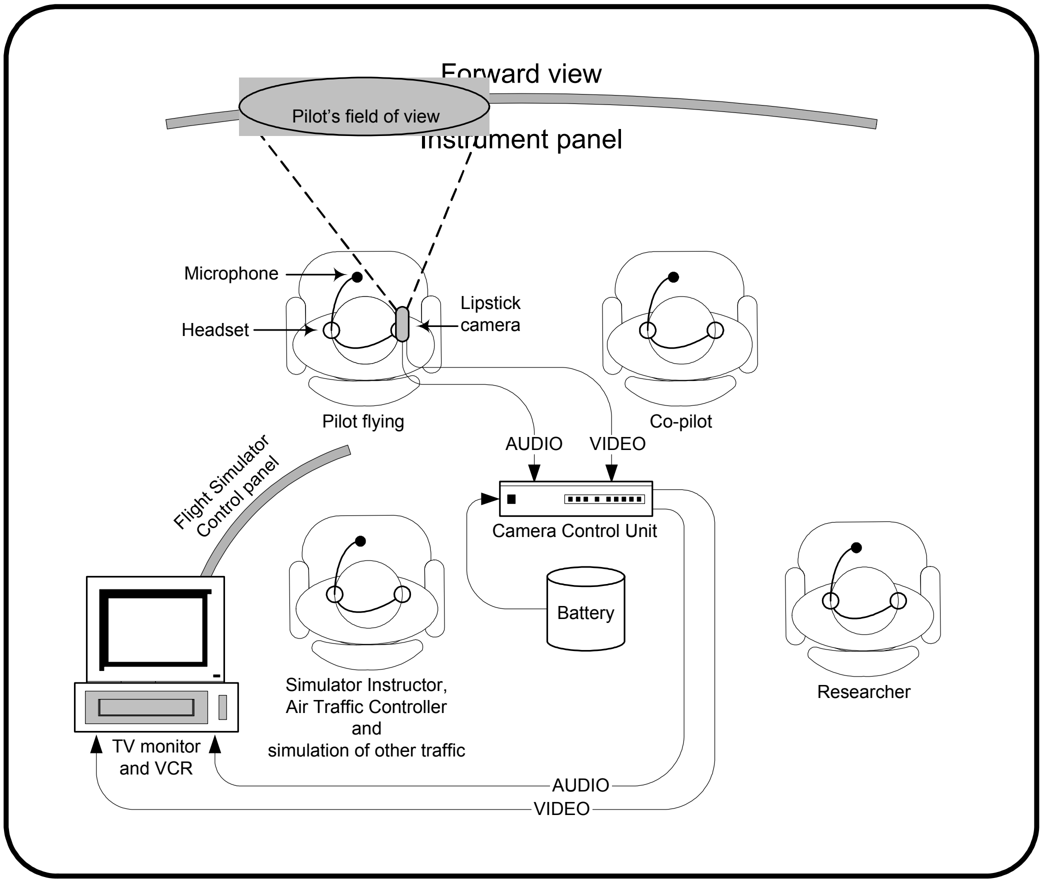


Figure 5.3: Flight simulator setup

The following equipment was used during the flight simulator sessions:

1. Sony DXC-LS1P 'lipstick' Colour Head Camera on a plastic band mounting
2. Camera Control Unit
3. Three batteries and a charger
4. Flight simulator TV and VCR
5. Pilot's headset with a microphone

A lightweight colour 'lipstick' camera was used, the same as during the preliminary study. It was attached to a plastic band that was adjusted to fit a pilot's head. The head-mounted camera was worn on the side of the head at the pilot's eye-level. Once the pilot donned the camera, and it was confirmed that the pilot was comfortably sited, the camera was adjusted in the direction of pilot's field of view. The pilot's field of view was monitored through a TV monitor visible only to the researcher during the flight.

5.2.3.3 Debrief room

The debrief room was set up in the same way as in the preliminary study. The set up (Figure 5.4) allowed the pilot to view and hear the same cues, as experienced during the flight. Such cues are discussed in detail as part of the preliminary study in chapter three and summarised in Figure 5.4. The master videotape recording of the flight was played back to the participant pilot on the TV monitor, and the pilot's comments from the debrief session were recorded on to a new 'debrief' tape. This debrief videotape captured the original image, plus any pauses that the pilot made in the video playback to make comments. All debrief comments were recoded in parallel to the original flight audio. The master videotape tape was paused when recording the pilot's detailed comments and answers to the researcher's questions. Consequently, this extended the duration of the debrief video recording to one and half hours.

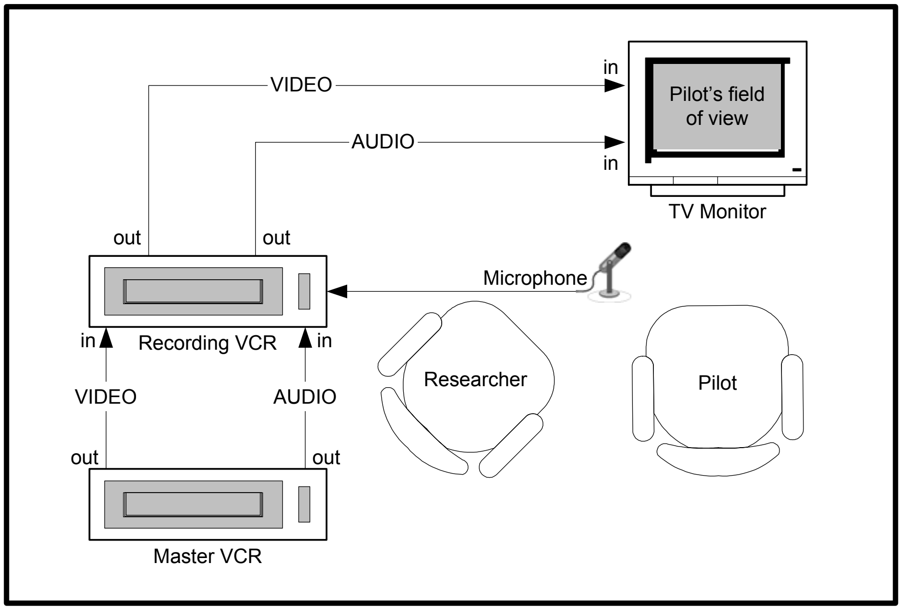


Figure 5.4: Debrief room setup

The following equipment was used for the debrief session:

1. Headphones.
2. Microphone.
3. Monitor.
4. Master VCR – Sony Hi-Fi Hi8 VCR and power plug.
5. Recording VCR – professional VCR with an Audio Mixer.
6. Various cables (4 twin RCA cable, 1 single RCA cable, BNC to RCA converter, 6mm to 3.5mm converter).

5.2.4 Task and Procedure:

All pilots were similarly instructed on, and taken through, the three-stage experimental procedure, consisting of the flight brief, the flight and the subsequent debrief of the flight. The flight brief consisted of informing pilots about the simulated flight, and additionally provided an opportunity for pilots' to ask questions, to read and to sign an informed consent form. The session in the flight simulator proceeded without researcher intervention, with the exception of adjusting the head-camera at the beginning of the session. The last part of the procedure was carried out in a debrief room, and consisted of a modified version of a cued-recall debrief (Omodei, Wearing, & McLennan, 1997) and a small questionnaire about pilot's flying experience (Appendix 3). During the flight, the flight crew consisted of two pilots only one of which wore the head-mounted camera. Only this pilot participated in the subsequent cued-recall debrief part of the experiment. All instructions and consent forms given to pilots were identical 3). This allowed consistency in the way pilots were informed about each stage of the study.

The information and consent session familiarised all pilots with the study and informed them of their right to withdraw and where to address questions after the study was completed. It also enabled them to ask questions before signing and agreeing to participation.

The flight brief briefed the crew on a routine flight from Richmond to Sydney, and included information on the weather, the airports and the route to take. After the head-camera was adjusted the researcher sat at the back of the aircraft simulator beside the simulator instructor. Each flight proceeded without interruption.

Each debrief session began with the researcher providing the pilot a 'Debrief Overview Sheet', which the researcher waited for the pilot to read. The recall session began with:

> Researcher: "Now, go back to the beginning of the flight and walk me through the flight. As you recall things, you can start talking and I will pause the tape if you start talking."

The videotape was played for a short duration…

> Researcher: "… you are just about to start, what kind of things are in your mind?"

At this stage the pilot would view the tape and start recalling events. The researcher would also prompt the pilot, if clarification were needed.

The debrief session would end with three additional questions:

> Researcher: (1) Now that you have watched the tape through… what, if anything, stands out most about the way you handled things?
>
> (2) If we could magically turn the clock back, what, if anything, you do different and why?
>
> (3) Suppose someone else less experienced than you had done this flight what mistakes would he or she been most likely to make?

For each separate experiment both pilot crew-members were observed during two flights; one with full use of automation, and another with minimal use of automation. A total of eight flights were observed and subsequently debriefed (Table 5.2).

Pilot	Automated	Non-Automated

		Flight	Debrief	Flight	Debrief
Crew A 24 October 2001	1	20 min	1 hour 30 min	20 min	1 hour 30 min
	2	20 min	1 hour 30 min	20 min	1 hour 30 min
Crew B 25 October 2001	3	20 min	1 hour 30 min	20 min	1 hour 30 min
	4	20 min	1 hour 30 min	20 min	1 hour 30 min

Table 5.2: Empirical / Observation Study set up

5.2.4.1 *Rationale behind automated and non-automated flight*

From primary observation of pilots in training, and in their on-line operation of aircraft, it became clear that there are differences in how automated and non-automated aircraft are operated. Additionally, during informal interviews of experienced and retired pilots, it was noted that whilst they reported that the introduction of the first automated features, such as an autopilot, which performed one or two functions (for example a constant climb or a constant speed), and this freed their time and effort spent on operating an aircraft; they reported as more automation was introduced to the cockpit, the pilot had to become more attentive in monitoring the automation's progress. Further, they added that as the automation became more complex, less transparent and had less resemblance to a 'pilot-like' operation, pilots less understood it and more operational problems were encountered. Consequently, it was considered appropriate to study pilots operating both automated and non-automated aircraft.

It was observed that pilots have difficulty operating automated cockpit systems; particularly in acquiring the required information they need from the displays, the flight management system, and also in understanding 'decisions' made by the automation. Additionally, it was considered that merely observing an automated flight might only highlight the workarounds that pilots have invented to deal with the recurrent problems with the automation. It is a well known fact in aviation that the Standard Operating Procedures that pilots use in flight are devised to help pilots to overcome such problems of poor automation design, which are also referred to as 'an indirect admittance of poor design' (Demagalski et al., 2002). Consequently, it was considered that observing an automated flight might only show one side of the story, that of pilots dealing with the shortcomings of current automated designs. Therefore, to avoid only observing the automation induced errors of pilots', from overly complex automation (Heymann & Degani, 2002), it was decided to observe pilots' operating aircraft with minimal (for aircraft type) to no automation.

Chapters three and four discussed how it was observed that trained pilots' appear to fly non-automated aircraft in an effortless and 'natural' manner. Additionally, in these chapters it was observed how initial pilot training provided the foundation for the way pilots' operate the aircraft; and how pilots' transfer previously learned knowledge to a new aircraft type. This is what is referred to as 'natural to pilots', 'pilot-ways' of use of information, and 'pilot-like' operation of non-automated aircraft. This contrasts with 'automation-induced' use of information and 'automation-like' aircraft operation. Observing a non-automated flight enables the manual retrieval of information to be studied. In addition, by observing non-automated flights pilot-ways of dealing with the information and pilot-like operation of the aircraft may be deduced. It is argued that this is the type of operator behaviour that needs to be supported with use of automation.

It could be asked, “why not just observe a non-automated flight?” However, it is contended that observations of both automated and non-automated aircraft operations are necessary, because pilots’ adapt and use different strategies of operation and different methods of collecting information in the different aircraft environments. Therefore, it is important to learn how pilots deal with the shortcomings of both settings. It is not claimed that automation does not help in the operation of the aircraft, but it is essential to learn where pilots use automation effortlessly or perform aircraft operation effectively with help of automation and where difficulties are experienced. The reason behind this work is to inform the design of automated cockpit systems. This study was set up to learn about pilot’s methods of obtaining and merging information from the cockpit and how this information is used throughout the flight. It is considered that this knowledge can then be translated in to design guidelines to help cockpit designers support pilots’ needs in their future designs of displays and interfaces for automated systems. With the aim that future displays and interfaces will be effortless and ‘natural’ to use.

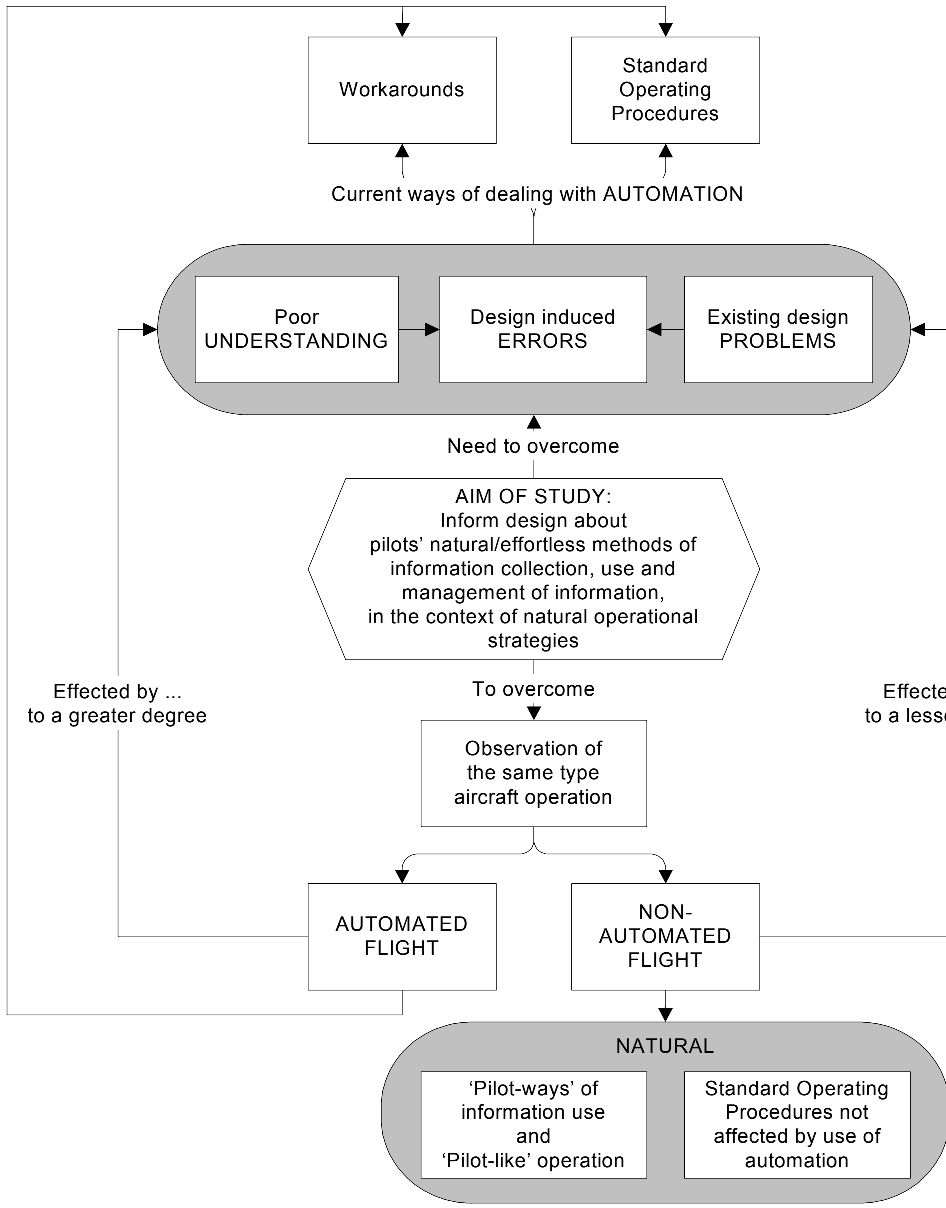


Figure 5.5: Rationale for observation automated and non-automated flight

The non-automation flight operation focused on pilots' use of basic levels of information available in the environment and the cockpit. In comparison, full use of automation in aircraft operation focused on how pilots' obtain information about aircraft state and the environment through maximum use automation.

5.2.4.2 Rationale behind observation of the whole flight

It was decided to observe the whole flight from power-up to power down, because the aircraft environment is time critical, dynamic and evolving, where current events are affected by past and present events and will affect subsequent events. Consequently, the information presented to, and sought by pilots' is also dynamic, constantly changing and dependent on evolution of all events. It is difficult to separate this information flow.

Pilots' deal with forthcoming situations that are full of information and these situations are dependent on the progress of the flight. However, it is argued that the study of only these isolated stages of flight will not show how pilots build on and construct information; or how information evolves and how having or not having specific piece of information affects the rest of flight stages.

5.2.4.3 Rationale behind questions present and future oriented

The information flow to be captured in the aircraft environment is dependent on evolution of past, present and intended future events. Asking only present-oriented questions only captures momentary strands of information. As it was showed in the discussion of training and on-line observations, pilots' constantly manipulate and use a continuous flow of information to support their work-flow in the constantly evolving flight.

There is a need to find what information pilots' use during the present to construct information about their future actions, and also a need to establish where they obtain any piece of information. Therefore, there is a need to ask, at any time, both present- and future-oriented questions to build up a continuous, evolving 'picture' of the flow of information. Consequently, the questions prompted by the researcher in the cued-recall-debrief method in the 'preliminary' study were oriented to finding pilots' present and future information needs.

The analysis looked for:

A. The information pilots use to identify the aircraft's state.
B. The information pilots use to anticipate the aircraft's next manoeuvre.
C. The sources of information pilots use to identify the aircraft's state.
D. The sources of information pilots use to anticipate the aircraft's next manoeuvre.
E. The method pilots use to assemble above collected information to identify the aircraft's state.
F. The method pilots use to assemble the above collected information to anticipate the aircraft's next manoeuvre.

Present-oriented questions examined what information pilots' required at that instant. Future-oriented questions were asked for the two following reasons. Firstly, the questions were asked to understand how and if pilots follow the fundamental rule of flying 'the need to stay ahead of the aircraft'. Therefore, there was desire from the researcher to know how far do pilots do stay ahead of aircraft, and what information do they need to collect and assess in order to be head of the aircraft in their mind. The second reason for asking future-oriented questions mirrors the rationale for observation of the entire flight, i.e., at any time of the flight the information pilots used was affected by current events and had an effect on future events. This was noted by the researcher during observation of pilots in training, in on-line operation, from the researcher's personal piloting experience (chapter 4) and, in the 'preliminary' study reported in Chapter three.

The form that the questions were presented to the pilots is in Appendix 3.

5.3 DATA ANALYSIS APPROACH

Results of any kind of study rely on the population it samples from. Once the sample is determined, the specific measurements are applied, and the data is collected and analysed. The data then is broken down further to be studied, either one small part of it is studied or all parts are studied separately. This is a reductionist approach, where the initial material/sample is broken down onto smaller and even smaller pieces as analysis progresses. However, the drawback is, that once all parts are analysed and put together to produce the studied entity or a system, it is never quite the same as where the material was taken from (Kugler, 2005).

There are several factors that influence the result of using the reductionism approach, three applicable to this study. Firstly, the sample is very small and therefore it is difficult to assess how representative it is. Secondly, the traditional statistical analysis of collected data eliminates outliers, (i.e. apparently extreme data points). However, these instances and properties of these causal factors may be significant (Bogatyreva & Shillerov, 1998). By eliminating such factors these are not analysed and consequently these cannot be reproduced. Finally, the methods used to capture, measure and analyse are not sensitive to capturing the instances and properties that are significant, and/or causal to the state of the system.

Additionally, the analytical method applied needs to take into account the unique property of the environment, i.e., the dynamics (please see the Box 5.1 for exploration of the property). Second, the method needs to be able adjust to study the whole system, complete with its parts, with minimal possible separation of the parts from the context and the environment.

DYNAMIC ENVIRONMENTS: *Internal and External*.

For example, the dynamic environment affecting nuclear plant operation is different to the dynamic environment that affects the aircraft. The dynamics of the nuclear plant environment are largely within the plant environment. In contrast, the dynamics largely affecting the aircraft are external to the aircraft.

The aircraft is affected by the current external environmental weather conditions it operates in. The weather dynamics in everyday operations are mainly unpredictable, but forecastable. The affects of the weather on the aircraft have to be compensated for by the effects of the pilot upon the aircraft.

The operation of the nuclear plant is affected by factors within the plant environment, where the fission reaction takes place. The operators have to maintain the dynamics of fission. If the dynamics of the fission reaction are not critically controlled and maintained, the results may be catastrophic.

To have a desirable outcome in aviation the operator has to make effects to compensate for external dynamic affects upon the aircraft, but the dynamic affects *within* the nuclear plant have to be critically controlled, and arguably only become unpredictable, like aviation dynamics, in a crisis situation.

Box 5.1: Dynamic environment

The information used by the aircraft pilot is dependent on their evolving workflow. The information sought, and used, by the pilot is influenced by, amongst other factors, interaction of data, their previous knowledge, the current context of the flight and the external environment. Therefore, analytical methods that comprise the fluidity of the of the workflow, or separate the workflow, will surely show an affect on the information needs of the pilot. Hence, in the investigation and analysis of the information needs of the pilot, throughout this thesis, there is a search for an approach to preserve the quality of the original environment (its fluidity, its dynamic properties, and its complexity). In the following paragraphs a naturally evolving approach to analysis is described. Using this approach the aim was not to analyse data without reference to its context

It is argued that the data acquisition and analysis has to be conducted by the same researcher. The possibility of another researcher undertaking the analysis was considered. However, due to sensitivity, confidentiality and unfamiliarity with the original study this option was abandoned. It is argued that in research of this kind it is vital that the same researcher conducts the data collection and sees the process of analysis, including the transcription, through to the end, where notions are crystallized. As O'Neill (p.113, 1998) noted "the process of transcription itself helps the analyst to become immersed in and familiar with the data."

The researcher found that in the process of transcribing each previously observed flight, the act of transcription acted as a 'zoom control' enabling minor details to be noted, details that otherwise, just from watching the tape and conducting the analysis from the video footage, would not have been obvious. For example, such details came from, listening, and rewinding each recording and logging different types of data, such as 'what triggered pilot to look for specific information at this point; where did the pilots acquire this information; what equipment did he use, if any?' This in depth approach gave a greater understanding to each piece of footage, an understanding that otherwise was difficult to capture. It helped to focus further analysis of each subsequent untranscribed video and audio record on more detailed information needs.

5.3.1.1 The Naturally Evolved Data Analysis

A conventional way of capturing video material is a view of an outsider (i.e., a fixed or moving camera) capturing participants' behaviour. However, the video and audio footage recorded in this study is of a different nature. The footage here is collected from the pilots 'own-point-of-view' with additional comments of the footage by the pilot. This contrasts to both, the recoding of footage by the subject of the footage, where they observe themselves in the footage; and also to the general recoding of footage by the researcher. The video and audio footage here is captured during the flight from very close to the pilot's 'own-point-of-view' consequently provides cues in the correct temporal order for "a high level of psychological re-immersion in retrieved memories associated with performing the original task" (McLennan, Omodei, & Wearing, 2000). This permits the pilot to recall every detail of what was going though his/her mind during the flight, at any point of the flight. This results in a second recoded audio stream (referred to as the debrief audio stream), which is recorded for the investigators benefit and analysis.

Omodei and colleagues (Omodei *et al* 1997) developed the head-mounted video technique to research psychological aspects of decision-making in real-world environments. To systematically analyse the cued-recall audio material they developed a cognitive process categorisation scheme (McLennan, Omodei, & Wearing, 1996) that focuses on tracing the detailed decision making processes of the subjects. This study, on the other hand, focuses on tracing information retrieval processes, and the use of information by pilots during a flight. Hence, McLennan et al's (1996) original coding scheme is not suitable. This study also required a different approach to analysis because, whereas McLennan et al (1996) only used a single audio stream generated by a cued-recall debrief for their analysis, this study required analysis of two audio streams. These are the original audio data, and the debrief audio, and also the original video footage.

The original flight audio stream was valuable in obtaining pieces of information that the pilot acquired in a conversation with Air Traffic Control, or with a co-pilot, or acquired through other audio signals, such as Morse code (for navigational beacon identification). Additionally, the original audio was valuable in obtaining cockpit audio signals, such warning and caution alarms and engines sounds. The debrief audio stream is of importance on two levels. One is where the pilot recalls events and triggers that prompted the recollection of required information for that moment of flight. The other level is that this highlights specific cues themselves on the original footage, therefore associating a specific cue to a specific information need and recollection of further information.

The video footage, although primarily recorded for the benefit of a pilot to help their recall of information processing, also generates an enormous quantity of data for the researcher. This data can be used to shed light on what information a pilot uses, where he/she obtains it, and what visual cues trigger recollection of a need for specific pieces of information. The data from automated and non-automated flight, and debrief was transcribed in separate tables with the anticipation of using the naturally evolved analysis developed and used in the preliminary study (Chapter 3). Examples of each flight footage and debrief (transcribed from beginning to end) can be found in Appendix 3. These transcriptions account for one-forth of all footage.

Initially, from all the transcribed footage, it was proving difficult to capture effectively the sensory cues that pilots were sensitive to, and those cues that triggered recall or need for specific information. However, these cues became obvious from watching repeatedly the original video footage of the flight and listening again to the audio recording of the debrief. O'Neill (p.109, 1998) states that 'encoding tend overly to simplify the raw data and thereby to lose richness and contextualised meaning.' This is exactly the difficulty that was found here using solely transcribed footage for analysis.

In the absence of a predetermined theory on which to base the coding and analysis, it was considered appropriate to avoid developing a coding scheme in advance of gaining data. Arguments such as those of O'Neill (1998) who stated, "what remains after filtering through a theory, encoding and applying statistics is far removed from the interaction data recorded on videotape, still further from the recorded event." It supports the need for the development of a coding scheme here considerate in preserving all aspects of the original data. Here, the aim of conducting an empirical study was to develop a notion of pilots' collection and use of information, without preconceptions. Hence, arriving with predetermined theory, notion or coding scheme it was considered would constrain the openness to the outcome of the analysis. However, once the data was analysed, the outcomes were grounded in existing notions and theories (Chapter 6 and 7).

Although the experience of conducting the preliminary study helped to evolve the method used in the empirical study (cue-recall-debrief), the results of the preliminary study *did not* influence the analysis of the empirical study. This was consciously done as it was considered that otherwise there was a danger that researcher would bring preconceived notions to the new study and so merely arrive at results that reinforced these notions. Following this reasoning the data analysis strategy is discussed below.

5.3.1.2 The data analysis strategy

The data analysis took an iterative progression through four stages listed below:

1. Search for answers to posed questions
2. Search for commonalities and patterns
3. Properties transpire/emerge and are identified
4. Search for transpired and identifies properties

The initial run through the stages of the analysis was similar to trying to spin a heavy wheel that took time to gain a momentum. However, with each subsequent run through the four stages the analysis became easier.

The first stages of analysis were tedious, as it was not clear exactly what is transpiring, seeing only the edges, but not understanding what it was forming in the analysis. This is the down side of this approach but also an advantage, because this allowed the researcher to have an open mind to what might transpire out of the data.

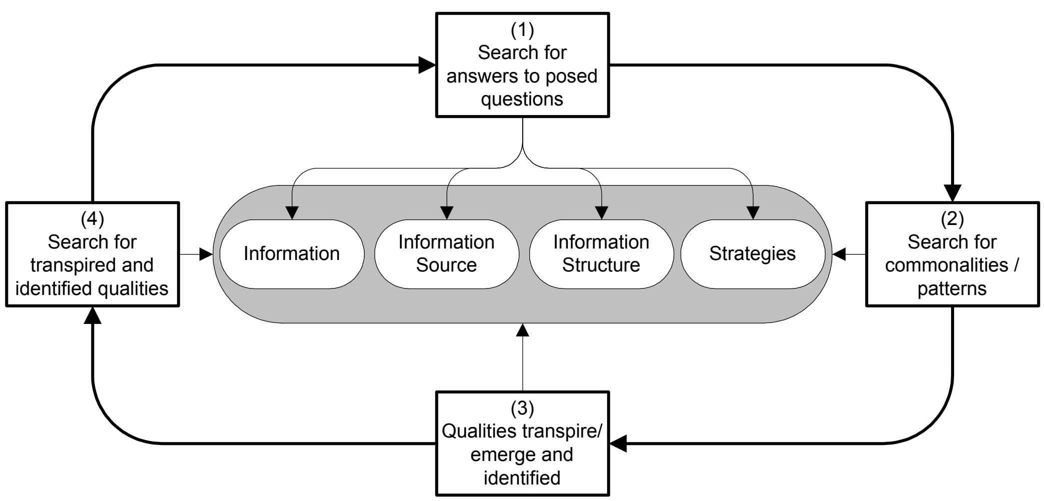


Figure 5.6: Strategy for data analysis

Given that the researcher had extensive domain knowledge this strategy avoided the distractions of being unfamiliar with terminology and the general layout of the information in the cockpit. However, if the researcher did not know the layout of information, it could also be helpful, giving a fresh outlook on the information structure. It would help to identify problems and concerns that transpire quicker because everything is questioned. This was certainly the researcher's experience when beginning the project with an immediate need to acquire an understanding the domain. This is when the research questions were formed and refined to become more specific as more understanding of the domain took place.

A set of questions identified in the problem statement chapter (Chapter 4) was used to begin the search at the first stage of the analysis. Each question, as discussed in the previous section, was both oriented to the future and the present.

Present-oriented questions:

i. What information do pilots use to identify aircraft state?
ii. What sources of information do pilots use to identify aircraft state?
iii. How do pilots assemble the above collected information to identify aircraft state?

Future-oriented questions:

i. What type of information do pilots use to anticipate aircraft next maneuver?
ii. What sources of information do pilots use to anticipate aircraft next maneuver?
iii. How do pilots assemble the above collected information to anticipate aircraft next maneuver?

The questions were deliberately general at the beginning of analysis. They were designed to point in the direction if interest, but not to limit the field of search too early. As the progress through four stages acquires more understanding, the questions become more specific and the mode is refined with every cycle through the stages (Figure 5.7).

To provide an example of how the analysis process refined the questions, let's examine the first question, "What information do pilots use to identify the aircraft state?" After the initial data analysis the information appeared to be in many forms. Therefore, this led to the subsequent questions that require more definition, such as, "Are there similarities among the information that pilots use?". Between stages three and four the similarities from the data in terms of groups or *types* are sought. Consequently, the next question becomes, "What *type* of information do pilots use to identify the aircraft state?" Approaching stage three, the groups/types become more refined and properties of each group become more distinct. Then the following question is formed, "Is there more information that match the identified qualities?"

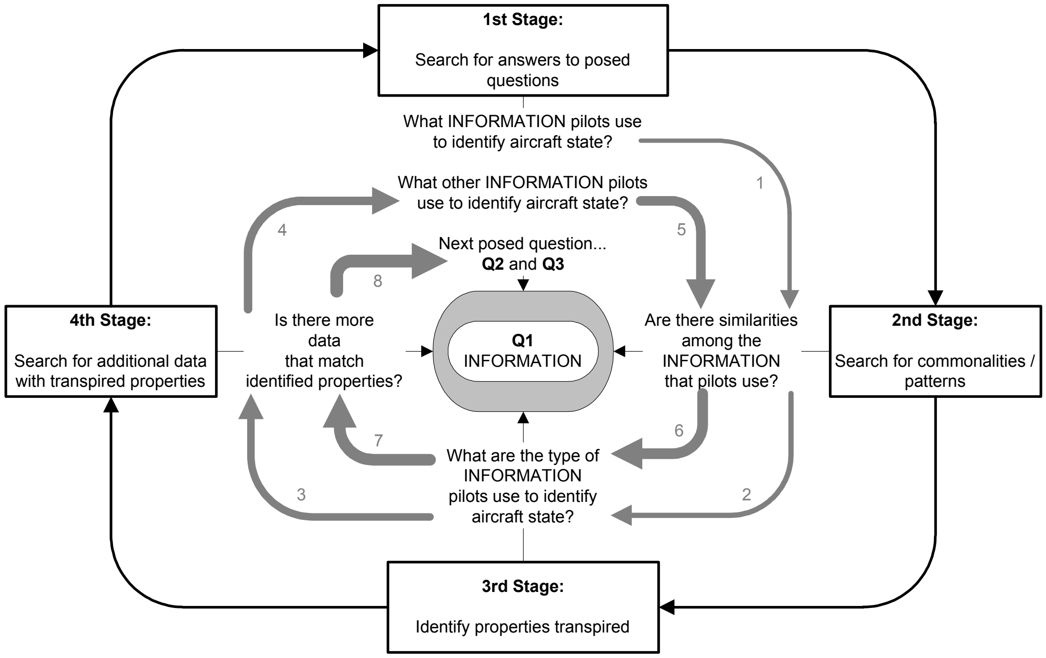


Figure 5.7: Refining the search

Each consecutive cycle through the four stages refines the questions further, for instance, following the previous example; the researcher would identify whether there are further information subgroups/categories and identify their similarities and properties. The data analysis continues through the four stages until the data cannot be broken down any further or additional analysis is not deemed to be required at this time.

The data analysis would continue by investigating the next general question posed, i.e., ”What sources of information do pilots use to identify the aircraft state?” This question is then refined through the four stages of the analysis in the same similar manner to the example shown in Figure 5.7. The analysis continues until all the posed questions are answered in detail.

As a final stage of the analysis all the gathered answers to the questions posed were organised in corresponding figures and tables. Each table had a definition of the group, a description of its properties and listed examples.

5.4 RESULTS

Sixteen videotapes were analysed (14 hours of audio and video material). Eight master videotapes consisted of four automated and four non-automated flights, including 20 minutes of flight footage from pilot’s point-of-view for each flight, plus eight tapes of one and half hour debriefs corresponding to those 20-minute flights with comments from each pilot, whose footage was on the tape. These cued-recall debrief videotapes had the original video footage of the flights together with an additional audio stream that contained pilots debrief commentary.

Initially, the data was transcribed. First the master tape was transcribed with the original audio/video and only then the debrief section was transcribed, which is a second audio stream on the debrief tape. The debrief audio stream transcription was synchronized with the original footage transcription, i.e., pilot's comments were inserted in the original footage transcription to match the original flight timeline (Table 5.8). That is, the original footage formed an initial column of flight 'events' for the table and then significant points from the debrief transcription were added as an additional column to match the flight events from the original audio/video footage) A sample of both, automated and manual flight transcriptions are in the Appendix 3.

It was noted in the 'preliminary study' that there is a need to maintain traceability of the workflow. This traceability is a desirable aspect that it taken forward for this data analysis approach. Traceability requires that the data are analysed in relation to its acquisition context. Further, when analysing parts of the data there is a need to keep in mind the properties and interdependencies of the context the data is acquired from. Some task analysis (Diaper and Stanton, 2004) techniques break down a workflow into tasks, goals, subsequently associating the information with particular tasks and goals, however, for this study this techniques may miss the important factor of the dynamic operating environment, the flow. It has been noted during the preliminary study that the uninterrupted, dynamic flow of information is crucial for pilots to perform effectively. The information is changing and evolving from the beginning of the flight to the end, from one task to another. No single piece of information exists on its own. The analysis strategy and the transcription table structure support this finding.

The master tape transcript was put into a table format (Table 5.9). From listening and watching the footage this approach appeared appropriate. In fact, a similar approach was taken in the transcription of the preliminary study; however, in these transcripts the column headings were different, except for the common 'TIMELINE' column.

The data analysis transcription table is organised with respect to the timeline (see left hand column). All the events, the dialog, the information flow is represented as it happened and annotated with against the corresponding timeline. This prevents disturbing the properties, the fluidity, dynamics and interdependencies of pilots' operating environment and the workflow. The sequence of all data is traceable and the evolution of information can be deduced. Other information of interest was also noted, such as goals, who is speaking to whom (FROM-TO column), Action-Planning-Monitoring (i.e., abbreviated as A-P-M column) tasks and objects used.

TIME LINE	**SEQUENCE OF EVENTS:**	**DIALOG**	**GOALS:**	**FROM -TO**	**A-P-M**	**DOING/ MONITORING/ PLANNING:**	**OBJECTS USED:**
00:00	FLIGHT PREPARATION (Setting up the cockpit)		Displaying reference maps		A	Locating, folding & placing maps for good accessibility during the flight	Paper location reference maps
			Displaying T/O charts		A	Locating & placing charts on control column	Paper charts
01:10	*Airplane Forms*: Data Entry		Data entered for the whole flight (as much as possible)		A P	Programming the system from T/O to landing	CNI
02:10			Radio data entry			Programming radio frequencies	AMU
…	…	…	…	…	…	…	…

Table 5.3: Fragment of the table

5.4.1 Data analysis – manual flight

The data analysis of empirical study was undertaken to:

- Trace the information pilots require for effective workflow;
- Trace whether and if pilots apply structure to information;
- Understand how pilots structure and use information to support the workflow;
- Trace whether the structure that a pilot apply to information is similar to observed during the training and operation (Chapter 4);
- Trace whether pilots use rules, techniques and strategies that are established in early flying experience.

5.4.1.1 Question (i): 'What information do pilots use to identify aircraft state?

The analysis began with identifying and collecting data to answer the first posed question, (i) '*What information do pilots use to identify the aircraft state?*' which explored the area of 'Information' in Figure 5.6. For the purpose of the investigation the *aircraft state* had a broad definition, and refers to the general physical state of the aircraft (i.e., internal 'health' of all systems), aircraft performance and also aircraft position in a navigational space and time.

The first run through the data was with question (i) in mind, and showed that pilots often used information that they '*referenced to*' or '*referred to*'. Consider the following example comments, all from the same flight:

Pilot 04:42 M: …also just quickly *referencing* in for the **airspeed** <u>for our rotate</u>.

Pilot 04:53 M: …All I am doing is <u>getting my attitude</u> & heading set on the PFD, so I'm concentrating on putting the **climb-dive marker** where I want it. …so I am just looking at the *reference*, the pitch ladder.

Pilot 04:53 M: …is looking down at the compass card and quickly referencing and having a look at the level on there as to <u>what heading I am flying</u>.

Pilot 06:42 M: …Just checking that generally <u>set the right height</u>, above the altitude tape there, checking **the cyan figure** …all of the *reference* number in a different colour, that they are the same, any *reference* figure is all in cyan. So if you see a blue *reference* number anywhere, that's it. That's a *reference* **number**.'

Pilot 08:11 M: Just checking in the ***Reference*** **Set panel** again <u>the brief altitudes</u> & the approach there

Pilot 10:42 M: …I wanted to *reference* the **VOR** to give me <u>tracking information</u> & needle pointer around the compass rose on the bottom…

Pilot 14:32 M: …TACAN means **DME**, so that I can have a *reference* to the **outermarker check-height**, <u>when</u> I am likely <u>to incept the glide slope</u>…

Pilot 14:32 M: …So I was just *referencing* down to **the distance** there at the bottom of the PFD to give me an indication so as to when I was going to intercept the finals course in the glide slope.

Pilot 17:55 M: … but mainly still just *referring to* those things I was scanning, **CDI bar, GS, rate of descent, Climb Dive marker, airspeed**. So it's all an internal scan on the PFD there…

An initial scan through the above comments shows the pilot referencing specific information, related to aircraft behaviour. It can be seen pilots reference several instruments either to verify current aircraft behaviour, or use the referencing information to identify the time to active next behaviour, such as in pilot comments on the 14:32 minute of the flight.

This leads to the second stage of the analysis (Figure 5.6) where the pattern of commonalities in the data begins to emerge. The pattern is related to timing – from the beginning of the flight, every two minutes throughout the flight the pilot references instruments to establish aircraft behaviour. The commonality among the information referenced by the pilot is summarised in the Table 5.4 below. Information, surrounding the word 'reference' relate to each other in a particular manner. The pilot appears to have identified specific pieces of information on individual instruments as references to determine aircraft behaviour. This can be defined as a property of referenced information.

The above paragraph also illustrates the fluidity and interdependent nature of the analysis and the difficulty of separating each stage of analysis from each other. The fluidity of analysis is similar to the dynamics of the workflow in the environment of the study itself. The dynamics of the environment are maintained in the analysis, as shown in the Table 5.4 below, where the researcher can trace specific information data, referenced by the pilot, without interrupting the flow throughout the flight.

Time	Flight Stage	Referencing	For
04:42	Take-off run	Airspeed	Rotate (i.e., taking off the ground)
04:53	After take-off climb	Climb-dive marker	Attitude
04:53	After take-off climb	Compass card	Heading
06:42	Initial Climb	Cyan figure/number above the altitude tape	Set the right height
08:11	Level-off	Reference Set Panel	Briefed Altitudes
10:42	Cruise	VOR (i.e., Very-high-frequency Omni-directional Radio range)	Tracking information
14:32	Descent	DME (i.e., Distance Measuring Equipment)	(Indication) when to intercept the glide slope

14:32	Descent	Distance	An indication when I was going to intercept the finals course in the glide slope
17:55	Final approach	CDI bar, GS (i.e., Glide Slope), rate of descent, Climb Dive marker, airspeed	An internal scan (NEXT LEAD to STRATEGY)

Table 5.4: Referenced Information #1

The third stage of analysis involves identifying the properties of already established information (Table 5.6). The transpired properties of the referenced information are:

- The information is referenced throughout the flight at similar intervals of time;
- The information is required to verify current aircraft behavior;
- The information is used as a *reference* to identify the moment of activation for the next behavior.

The last of these properties leads to two further questions, which, although apparently out of sequence presented here, is in fact how, in practice, the questions transpired. The first question is, '*What is it in a reference that signifies the next behaviour/action/event?*, this intends to identify more detail about the information, and is the question for the second iteration through the four stage of analysis. The second question, '*How and when do pilots identify the reference for the flight?*, intends to explore pilots' strategies of assembling information. This is also a part of the analysis (Figure 5.6), but given the fluidity of the analysis, the strategy is connected to specific information and can be observed throughout the flight around the referenced information. These questions will be expanded on in detail at more appropriate juncture later in this section.

The fourth stage involves searching for more information that matches the described properties examined during stage-three. Running through the data for the second time, the word 'constantly' appears in the data on several occasions. This is the first property identified, i.e., *'information referenced throughout the flight at similar intervals of time'*. To make sure this is the same type of information, two further properties have to be present in these pieces of information. Consider the following transcript:

Pilot 06:28 M: …he is *constantly* watching, if I haven't bust a height (i.e., pilot jargon for – to break Air Traffic Control altitude restriction), airspeed or a heading or whatever…

Pilot 11:10 M: …I'm watching the speed caret come up and go above the wing, because we want to accelerate, but as to how much that go before you get to 210 knots it's something that I had to *constantly* monitor…

Time	Flight Stage	Referencing	For
06:28	Initial Climb	Height, airspeed or heading	Watching (i.e., monitoring) for not to

			break Air Traffic Control restrictions
11:10	Cruise	Speed caret	To signify acceleration

Table 5.5: Referenced Information #2

The timing of pilot's comments again falls in to the two minute intervals of the transcript. The property of information is also relevant to aircraft behaviour, for both verifying current aircraft behaviour (see comment 06:28) and for identifying the moment of activation for the next behaviour (see comment 11:10).

Two new words arise in the data that are relevant to this type of *referenced* information, '*watching*' and '*monitor*'. The word '*monitor*' appears to be more a strategy, and this will be explored in the strategy search section of analysis. However, merely identifying a word, such as 'watching' or 'monitor', does not immediately signify that all information surrounding this word will match the searched properties. The information surrounding the word must be compared against the properties established at this point (i.e. an already established property here is *'information referenced throughout the flight at similar intervals of time'*) before considering the surrounding information with data collected already of that type. However, the information surrounding the word may match several, or all, the properties, and it may also elucidate new properties or even refine already established properties. The word 'watching' does exactly that, generating new properties, which can be seen to transpire when the pilot's full comment is reflected upon:

Pilot 11:10 M: …Just putting the power up there, obviously I'm *watching* the speed caret come up and go above the wing, because we want to accelerate, but as to how much that go before you get to 210 knots it is something that I had to constantly *monitor*, once I got to 210 knots, then I had to pull power back to make sure the caret was on the wing. So it did not raise the workload a great deal, but it did a little bit. There is nothing that really tells you after 210 knots at this height you need to set this power.

From this reflection the new property of '*referenced information*' transpires. The reference for the information appears to be *'compared to some other feature', assessing this comparison* establishes the information's correct or wanted/required position. It is shown in the two comments, '*I'm watching the speed caret come up and go above the wing*' and '*then I had to pull power back to make sure the caret was on the wing*'. The referenced information is the speed caret symbol and it is compared to a stationary, or relatively unchanging, reference of the wing symbol on the display. In the first instance of this property, '*…the speed caret come up and go above the wing…*', the pilot was anticipating aircraft behaviour, *'...because we want to accelerate…'*. The pilot was expecting the speed caret symbol to move above the wing symbol. The wing symbol was chosen because it was stationary and did not change its position relative to the speed caret symbol. In the second instance, '*…make sure the caret was on the wing…*', the pilot was monitoring aircraft speed performance, which had to be kept constant, *'I had to constantly monitor, once I got to 210 knots'*. In the same way as in the first instance, the pilot here monitored the aircraft performance against the same feature, because it was unchanging relative to the speed caret. Hence, in both instances the *referenced information* would have no significance if not referenced against another feature that was *constant* and *unchanging* relative to the monitored symbol.

The discussed property of *'referenced information'* is now established, however, to make sure it is not only specific to this piece of data, a subsequent run through the already collected data is required. Following this, all the data has to be analysed again considering *all* the established properties. This is done, as there is a possibility that the formerly established properties are dominant in the collected data, but the latter property is weaker and so not as pronounced.

While establishing properties of *referenced information* a problem was noted evident in the following transcript sentence, "*…There is nothing that really tells you after 210 knots at this height you need to set this power…*". To keep the fluidity and to maintain the flow of the analysis, the problems are noted with the timestamp (M 11:10) and later investigated if they are related to the property studied. If the problem is related to it, the problem is systematically analysed through the four stage of the analysis, for similar problems, commonalities and properties.

The question posed earlier for further detailed analysis, '*What is it in a reference that signifies the next behaviour/action/event?*', appears to be related to the latest established property, i.e., the *referenced information* is always located relative to a constant and unchanging symbol. The only difference between the question and the property is that the posed question refers to anticipated aircraft behaviour and the property refers to both anticipated and current monitored aircraft behaviour. In other words, the latest property is the answer to the newly posed question. That is, the constant and unchanging symbol relative to a moving symbol is a *reference* that signifies the moment for the pilot to execute a new behaviour/action/manoeuvre/event.

The table below shows all of the established references against all of the pilots comments listed previously (Table 5.6).

Time	**Flight Stage**	**Referencing/ Watching/ Monitoring**	**References – constant and unchanging**	**For**
04:42	Take-off run	Airspeed	Rotate Airspeed Indicator on speed tape	Rotate (i.e., taking off the ground)
04:53	After take-off climb	Climb-dive marker	Pitch Ladder Bars	Attitude
04:53	After take-off climb	Compass card	Heading Marker	Heading
06:28	Initial Climb	Height, Airspeed or Heading	Altitude Caret, Airspeed Indicator and Heading Marker	Watching (i.e., monitoring) for not to break Air Traffic Control restrictions
06:42	Initial Climb	Cyan figure/number	Digital Altitude readout and Altitude	Set the right height

		above the altitude tape	Caret	
08:11	Level-off	Reference Set Panel	Set Altitudes, reflected as a Altitude Carets	Briefed Altitudes
10:42	Cruise	VOR	Needle (or Bearing) Pointer	Tracking information
11:10	Cruise	Speed caret	Wing symbol	To signify acceleration
14:32	Descent	DME (i.e., Distance Measuring Equipment)	Stationary beacon on the ground, signified by a sound, when the aircraft passes over it	(Indication) when to intercept the glide slope
14:32	Descent	Distance	Navigation Source/Data, generally specific coordinate	An indication when I was going to intercept the finals course in the glide slope
14:51	Descent	Height, Airspeed and Compass Card	Horizon Bar, Digital Speed Window and CDI (i.e., Course Deviation Indicator)	Staying level, monitoring speed and intercepting finals course
17:55	Final approach	CDI bar, GS (i.e., Glideslope), rate of descent, Climb Dive marker, airspeed	Stationary symbols on the Primary Flight Display	An internal scan (NEXT LEAD to STRATEGY)

Table 5.6: Established Information

As with previous analysis, the data in the above table (Table 5.6) went through a four stage analysis cycle to search for further patterns, commonalties and new properties within the data. A new property emerged; in all the references the pilot used not only these references, which were constant and unchanging relative to monitored symbols, but they always *associate/relative to/relate to some other symbology* on the display. For example, the Pitch Ladder Bars are positioned relative to the Horizon Bar.

The data analysis was concluded for the first posed question, '*What information do pilots use to identify aircraft state?*', by extracting all the comments surrounding the words '*watching, looking, checking and concentrating*', as these words arose during the analysis of the data against this question. This remaining data was then put directly in the above table if it matched the identified properties. However, during this final cycle of the analysis it was found that previous cycles were so thorough that there was only one more specific comment to include from the data into the table.

The comment (14:51 M) from the data contained combinations of *referenced information* that extended the established properties; consequently it was considered that the comment required more detailed analysis. In the comment the pilot says that he is concentrating on "*…quite a few things…3 to 4 different things…*". The more detailed analysis indicated that all of the *referenced information* appeared to have conditions or boundaries defining it, which are not obvious on the aircraft instrument display. The table below (Table 5.7) further breaks down the comments into three columns, (a) what the pilot is concentrating on, (b) conditions or boundaries that the pilots has to consider, and (c) specific *referenced information*.

Concentrating on…	**Conditions/Boundaries**	**Specific Referenced Information**
1. Staying level	(a) I cannot leave 3000 feet until I intercept that glideslope; (b) and established within tolerances for the approach	(a) Predetermined condition defined by a position in space; (b) and a space within specific boundaries
2. Decreasing airspeed	(a) So that we can get the landing gear down; (b) but not keep washing the speed off	(a) Restricted safe for landing gear airspeed; (b) Specific lower and upper margin of the airspeed to remain within
3. The compass card	I am seeing that the Course Deviation Indicator (CDI) which is that bar in the center of that white thing to intercept my correct azimuth there	Expecting referenced information to cross and <u>become a complete symbol</u> (FEATURE/PROPERTY)

Table 5.7: Conditions and References

From analysing the data further it was apparent that when the pilot is concentrating on '*staying level* '(Table 5.7- row 1), he appears to have a predetermined point in space, which is not represented on the display, and therefore, it was reasoned, he is probably referencing a 'mental' representation. By similar reasoning it was considered that the same is true for the comment, "…*within tolerances*..." (see 1b in Table 5.7- row 1); only this time it is a space within specific boundaries that is not clearly on the displayed on the aircraft instruments, but, is represented in the pilot's mind. In order to stay level the pilot has to satisfy both referenced information, and all conditions and boundaries. Also, when the pilot is concentrating on '*decreasing airspeed'* (Table 5.7 – row 2), it is reasoned, he appears to have a specific speed in mind that is set between boundaries For example, below this speed the landing gear can be safely lowered, but once this speed is achieved the speed cannot be allowed to decrease further, as this could result in the aircraft stalling (i.e., a condition when there is not enough air passing over the wing and as a result the aircraft cannot maintain the altitude). Additionally, when the pilot is concentrating on the '*compass card* '(Table 5.7 - row 3), he appears to have a picture in mind of how the referenced information should align before he can initiate the next event. In this way the pilot appears to be expecting the display to match the picture in his 'mind'. This use of information by pilots can also be describe as a strategy and is discussed in the Strategies section of this chapter.

Pilot 14: 51 M: …I'm watching the compass card and seeing that the Course Deviation Indicator (CDI) which is that bar in the center of that white thing to intercept my correct azimuth there...

In all of the 'Concentrating on…' cases listed in the above table it is reasoned that the pilot had a mental representation of the *referenced information*. It is argued that the aircraft instrument display only then provides the space where the pilot 'places' (i.e., places mentally) his *referenced information*, such as altitude and speed tolerance margins.

In the 'Concentrating on…' cases of *'staying level'* and *'decreasing airspeed'* the *referenced information* was concerned with maintaining conditions and boundaries. In the case of the '*compass card*', *referenced information* was a condition to be reached to trigger the next event. To summarise this, a new property of the *referenced information*, is that it can be either *a reference to maintain* aircraft behaviour (by using aircraft performing characteristics, such as airspeed), or it can be *a reference to do something*.

Comment (14:51 M) helped to identify another new property of referenced information, that, *referenced information can be linked to create specific conditions and boundaries* for aircraft behaviour. The comment also helped to differentiate between all the referenced information identified prior to this comment. All previously identified *referenced information* was displayed in the cockpit, however, *referenced information* identified in the this comment (summarised in the table above) was represented in the pilot's mind and was 'placed' on the display by the pilot to define conditions and boundaries. This is referred to here as, information of an internal type (i.e., in pilot's mind), the converse being, information of an external type (i.e., information depicted on a display). These last findings led to the second posed question 'What sources of information do pilots use to identify aircraft state?'. For example, two possible sources; *external* i.e., visible on the display, and *internal*, i.e., in the pilot's mind, have just been discussed. However, prior to proceeding to the next posed question, it is necessary to group *referenced information* and summarise the identified properties. The pilot used *referenced information* that can be put into three groups: aircraft configuration; aircraft behaviour; and outside referenced information. What is included in these groups of referenced information is tabulated below.

Referenced Information related to …		
Aircraft configuration	*Aircraft behaviour*	*Outside*
Engine performance	Airspeed	Turning points
Flap position	Climb/descent rate	Air Traffic Control contact points
Landing gear position	Angle of climb/descent	Altitude
Aircraft bank	Rate of turn	Distance
	Heading	Runway dimensions/ gradient/ perspective
	Specific lower and upper margin of the airspeed to remain within	Navigational points
		Glideslope

		VOR (Very-high-frequency Omni-directional Radio range)
		DME (Distance Measuring Equipment)
		Space within specific boundaries

Table 5.8: Referenced Information related to

These are the properties of *referenced information* identified to this point of analysis:

- Referenced throughout the flight at similar intervals of time
- Required to verify current aircraft behavior
- Required to maintain aircraft behavior
- Used to identify the moment of activation of next event/behavior/maneuver
- Connected to other feature/or relative to them
- Compared to other features on the display
- Expecting referenced information to cross and becomes a complete symbol
- Constant and unchanging a Reference (i.e. unchanging) and Referenced Information (i.e. changing)
- Linked to create specific conditions and boundaries
- Pilots have a picture in mind of how the referenced information should align and manipulate the aircraft to accomplish that

The last point in the list above can also be considered a strategy that pilots use to manipulate information and is referred to in the section, Strategies.

5.4.1.2 Question(ii): 'What sources of information do pilots use to identify aircraft state?

The same four-stage analysis used for the previous question was used to search for the sources of information that the pilots use (Figure 5.6) Through the analysis at least two distinctive sources of information that pilots use were identified. These two information sources contrasted in that some information used by the pilot had an obvious visible source, whilst the other type did not have an obvious source, and appeared to come from the pilot himself. Visible sources of information were labelled as an *external*, and the latter as an *internal* source of information.

The properties of *internal* and *external* the information sources began to emerge as individual examples were considered (Figure 5.6). From the transcript and video data analysis, the external source of information included information visible on displays or visible on paper, such as on maps, navigational plates, and manuals.

> Pilot 03:08 M: All that is just interpreting what's *on the plate* there & by briefing it, it's actually putting into, right in to our minds, instead of always refer to it, some of it can be done from memory.

In comment (03:08 M) above, the pilot is looking at the departure plate for a planned runway. The plate is a piece of paper that contains navigational information for a specific place, such as an airport, and details, such as, the navigational point for an approach or departure from a specific runway. The pilot is briefing both himself and the co-pilot (i.e. the crew) on the next several steps they have to complete during a departure. The pilot is using an external source of information and, "…putting right into their minds…" the points for them to remember to complete. This then becomes an internal source of information for the crew (Figure 5.8)

There were also other sources of information that came to the cockpit from outside sources, for example the radio, navigational beacons (i.e., Morse code) or from the Air Traffic Control, these too are considered external sources. Below, in comment (ATC 07:32M), is an example of Air Traffic Control (ATC) being an external source of information.

ATC 07:32 M: 'Roger, Sydney terminal information Alfa, Runway 07, wind 120 degrees, 10 knots, QNH (i.e., air pressure) 1022, temperature 15, expect ILS (i.e. Instrument Landing System) approach.'

Comment (ATC 07:32 M), illustrates the pilot obtaining information from the Air Traffic Control, about the weather at the destination airport and the announcement of the new runway change due to the mentioned weather change. This external source of information would also include information that the pilots obtain by looking out of the cockpit.

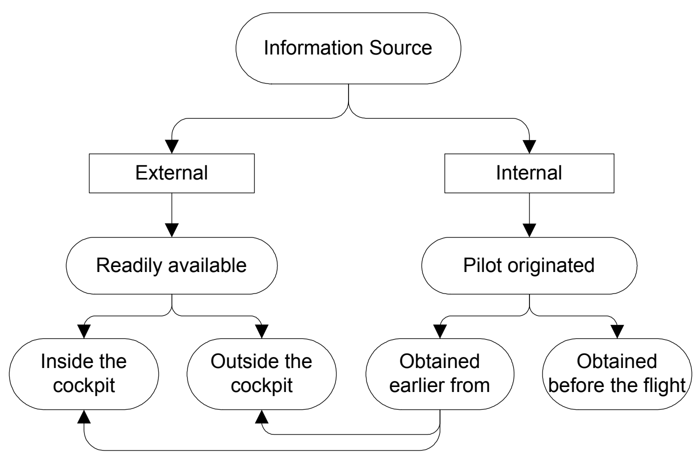


Figure 5.8: Information sources

Internal sources of information refer to information that the pilot has obtained during or before the flight, and such an example is described the above comment (Pilot 03:08 M). In this comment the pilot 'internalised' some information by memorising several pieces of information to recall at the appropriate time during the flight. Internal sources of information also include information that was not provided in the cockpit, but which is pertinent to the flight. One example of such information was when the pilots 'placed' on the airspeed tape lower and upper limits for the aircraft to remain within. The limits were not physically displayed on the airspeed tape, the pilots had 'placed' the limits there in their minds. An example of this can be seen in comment (Pilot 14:51 M) below.

Pilot 14:51 M: …The other thing I am looking for my airspeed to be decreasing, now so that we can get the landing gear down, but not keep washing the speed off …

From the above comment it is not obvious where the pilot has obtained the information. This comment is typical of those from the data and demonstrates a general technique of the data analysis. To ascertain the unknown information source, the source of the information was queried by the researcher at the debrief. The pilot's response would be then guide the attention of the researcher, possibly to a past moment in the flight whereupon this would be investigated and questioned further. For example, a note would be made by the researcher during the debrief, questioning how did the pilot know and store this information, and also, how was he able to pull out, or access, this information at the correct moment in the flight. This type of approach, of collecting and analysing data, is an example of how an analysis can be flexible enough to divert and adapt to pilots search for information; permitting the researcher to note appropriate areas of further investigation, to note links that the pilot has made in the information, and also to what 'triggers' the pilot has, or relies on for their stored information access. This flexible and adaptive data analysis, following pilot's search, also permits the maintenance of the fluidity of the dynamic environment in which the operation of the aircraft happens. This is an advantage of this naturally evolving analysis.

5.4.1.3 Question (iii): How pilots assemble above collected information to identify aircraft state?

As the data analysis progressed it became clear that the pilot had strategies for collecting information, but also that *referenced information* already had structures that assisted pilots in assembling information. Both structure and strategies are discussed next.

5.4.1.4 Structures

As the analysis proceeded through the same four stages, structure became evident in the *referenced information*. Structure in this context is referred to as specific information that is 'linked' by pilots.

It was found that most of the external type information had structure. The structure was either observed as imposed by physical aspect in the cockpit, such as *a display information layout*, or that of *the navigation plate*, or it was imposed by *an operating procedure*, such as making *an Air Traffic Control call*. During the Air Traffic Control (ATC) procedure ATC first mentions to whom the call is addressed, because everyone on the transmitting radio frequency hears the call. This attracts the attention of the appropriate crew. Next ATC inform the crew which runway and type of departure they are expecting the crew to follow, '*Glenfield* (navigation point) *One* (referrers to the runway number and direction 010) *departure* (expected action)', followed by instruction for the crew to execute, '*climb and maintain 3000*' and clearance instruction. The pilot's response to ATC is also structured. First, the pilot acknowledges their location and intended departure via Glenfield, then acknowledges the Air Traffic Control instruction by repeating the instructions back, stating their clearance for take-off, and finishing with their call name (see comment ATC 04:17 M).

ATC 04:17 M: Call Name 123, Glenfield 1 departure, climb and maintain 3000, clear for take-off.

Pilot 04:23 M: Glenfield 1, 3000 clear for take-off, Call Name 123.

The comments below are of interactions between the crew and ATC. Occasionally, the pilot initiates these interactions; for example, when they have reached a reporting point or require a clearance. However, generally the Air Traffic Control initiates the interaction; for example in the comments below ATC give a speed restriction (comment ATC 10:55 M), but other interactions may be initiated by ATC, such as the need to indicate relief of a restriction. The structure of the call and the acknowledgment of the understanding the instruction by pilots follow the same structure. Pilots already had a communication with this ATC station, therefore there is not the introduction of who is speaking, but rather to whom the call is addressed, followed by the request, instruction or restriction. The reply by the pilot is the response or acknowledgement and again each comment finishes with their name.

ATC 10:55 M: Call Name 123, report airspeed.

Pilot 10:59 M: 200. Call Name 123.

ATC 11:01 M: Call Name 123, if you could increase to 210, thanks.

Pilot 11:04 M: 210, Call Name 123.

However, this structure is altered when there is change in the weather, or the change of operating runway. In these cases the ATC broadcasts the call to all aircraft on that frequency (see ATC 09:51 M). The acknowledgement in this case is not required if it does not affect the crew immediately. In the example of comments below the aircraft is close to the airport, and so the ATC follows the general call with a specific call addressed only to this aircraft, positioning them third in the queue of aircraft to land in the new operating runway.

ATC 09:51 M: All station in bound Sydney, Sydney terminal information BRAVO is about to be recorded duty runway 16R, switch now, 140 degrees, 15 knots, QNH 1022.

ATC 10:09 M: Call Name 123 we will make you number 3 in the sequence, turn left heading 045 to intercept the 12 mile arc for 16R ILS.

Note that in the above example the Air Traffic Control announces a special announcement, called *ATIS* (i.e., Automatic Terminal Information Service), which also has a specific structure. The ATIS contains information about active runway/s, wind information, such as direction, '*140 degrees*' and wind velocity '15 knots', an altimeter setting, '*QNH 1022*' (i.e., air pressure), followed by more detailed information about the weather, such air temperature, cloud level, visibility and any additional significant items on local weather. Without knowing the structure of information and expectation of specific information the words, '*140 degrees, 15 knots*', have little meaning, but in the context of ATIS announcement it is information about the wind on the corresponding runway.

The following example, taken from the analysis, demonstrates two ‘information structures’ that are interdependent. The first structure is that which is physically imposed by the layout of the navigational information printed on the departure page of the relevant airport, termed in aviation the *‘plate’*. In preparation for the departure pilot and co-pilot brief each other with this information using the structure it is presented on the layout of the plate. The second ‘structure’ is that of the encompassing procedure that the pilot and co-pilot follow to commit this information to memory. This ‘structure’ involves the pilot reading the required navigational information out loud from the plate, whereupon the co-pilot confirms that he has heard, and agrees with what is termed in aviation the ‘departure plan’. Therefore, during this structure pilot and co-pilot need to submit this departure information to memory (i.e., internalise the information), because once the aircraft is rolling and during the initial stage of climb their time is limited, with events happening very quickly and consequently there is little time to for rereading the plate.

The table below provides details of the surrounding events related to the *‘information structures’* discussed above. In the table the ‘dialog’ column contains the original flight transcript and the ‘comment’ column provides the pilot’s comments. The pilot’s comments detail how the pilot memorised the information in a specific order that was a combination of the specific order provided on the ‘plate’ combined with the operating procedure.

TIME LINE	**SEQUIENCE OF EVENTS:**	**DIALOG**	**COMMENTS BY THE PILOT DURING THE DEBRIEF**
03:08	TAKE-OFF briefing	‘Glenfield 1 departure out of here runway 10; plate stated 4 October 2001, no amendments; gradient required 3.3%, which we can do; track 095 and 1TAC or 1000 feet, which ever is later, turn right, track 170 to intercept 144 for Richmond NDB, track to Glenfield then as cleared.’ ‘*Copy*’	‘All that is just interpreting what’s on the plate there & by briefing it, it’s actually putting into, right in to our minds, instead of always refer to it, some of it can be done from memory. And usually what I will do with departure, some of the departures would be quite long and complex. However, you really cannot keep all of that information in your head, so what you do is brief the First (i.e., First Officer – the co-pilot) or you just remember two to three instructions, so like maintain heading 095, 1000 feet or 1 TAC. Next what I’m going to do is turn, right turn on TACAN distance. TACAN is …a type of DME (i.e., Distance Measuring Equipment).

Table 5.9: Transcript extract – Information Structure.

The original dialog begins like that of the ATC call, with information communicated to confirm that the source of the information is correct, ‘*Glenflield One departure… runway 10*’ and then the date is stated to assure the particular ‘plate’ is the current document. Next the information proceeds in a sequence that would match the unfolding events during take off. First, the physical properties of the runway are established, ‘*gradient required 3.3%*’ (the slope of the runway), followed by the direction of the flight, next a point in space is established which would mark the beginning of the next manoeuvre, i.e., ‘*the right turn*’. At this point the order of information repeats itself, with the direction of the flight communicated then the next point in space to mark the next manoeuvre communicated. The pilot’s comments show that the pilot memorises (internalises) only the first sequence of information until the first manoeuvre, before the structure of information starts to repeat itself. Following the original transcript, dialog and comments, along the timeline of events shows where the pilot obtains the information he uses, and that the structure of both the 'plate' and procedure dictates how the pilots memorises (i.e., internalises the information) the information.

5.4.1.4.1 Operating Procedures and Checklists

Other examples of 'information structure' found from the data analysis were in *operating procedures* and *checklists*. For example, in the after take-off checklist 'information structure' can be observed in the caption below (caption: Pilot 05:21 M). The spoken checklist structure here matches the order of the executed actions listed on the written checklist.

> Pilot 05:21 M: … Landing gear up, flaps up, after T/O checklist.'

5.4.1.4.2 Structured information beneficial to memorising and recall

From the data analysis instances were found where the structuring of information appeared to be helpful to pilots in enabling them to better recall and execute actions. For example, this type of structuring of information happens during briefings, such as the brief before the flight (i.e. 'take-off brief'). However, this structuring does not, from the data, appear to be confined to formal briefings, it appears a more general strategy that pilots employ to help them remember information at crucial points during the flight. Below is an example of a pilot briefing the approach at 11:16 minutes that uses information structure as a strategy to help the pilot to recall it 7 minutes later in the same flight at 17:55. Again, the information is structured along the timeline of the flight, announcing the events in the order, as they would happen later in the flight.

> Pilot 11:16 M: 212 NDR MINIMUS radar set to 212. Outermarker check height 1295 at 4.7 I'll give you localiser frequency when you are turning…

> Pilot 17:55 M: I am also, next thing I'm looking at validating the ILS by that outermarker check height again. And PNF (i.e. Pilot-Not-Flying) briefed a little bit before, as to what the height (i.e. 1295 feet), distance (i.e. 4.7 miles) we were looking for, so that's a next step.

5.4.1.4.3 Internal and External Information Structures

In a similar manner to sources of information, structures can be classified as *external* and *internal* (Figure 5.9). External information structures are based on procedures, like in the examples above of the ATC communication, and also the example where the pilot briefs the crew of the departure plan. These are classed external information structures as they are 'imposed' or 'given' structures either inherited from the equipment layout (e.g. Flight Management System), or from documentation structure, such as the *plate* introduced earlier as an example. From the data, it appears that most of the internal information structures, i.e. those generated by the pilot, appear to originate from the use of external structures, training and prior pilot training and experience.

5.4.1.4.4 Information Structures Relating to Time

There is also a special category of information structure relating to time (Figure 5.9). This information structure is the most often used structure throughout the flight, featuring in most operating procedures, such as in the example above (see examples 03:08; 05:21; 11:16). It generally follows the order in which the tasks are executed (i.e. the pilot briefs all stages of flight and also during debrief using a timeline).

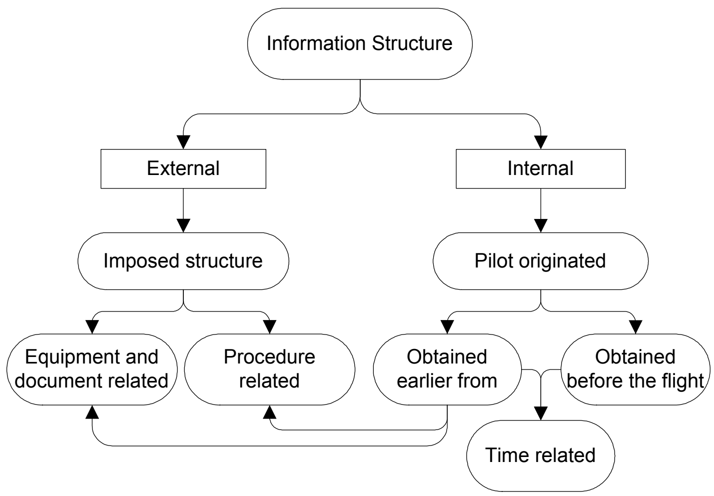


Figure 5.9: Time related Structures

The timeline structure appears helpful for pilots in their recall of the required information, such as in the example below, where the pilots is referencing information to identify the time to activate the next behaviour. The timeline appears to play an important role in the pilot's use of strategies and it is discussed later in the strategy section.

> Pilot 14:32 M: …So I was just referencing down to the distance there at the bottom of the PFD (i.e. Primary Flight Display) to give me an indication so as to when I was going to intercept the finals course in the glide slope.

External and internal information structure properties are different (Table 5.10). From the data it is apparent that pilot's internal information structures are recalled more easily, more flexibly, are more easily adaptable and are less restricted than external information structures. For example, when pilots received information about the runway change, the pilot discarded the old runway information and immediately started to brief for a new runway. However, the information entered in the systems for the approach to the new runway had to be changed (such as radar information), and new approach plates needed to be found, even through in reality it was the same location, Sydney airport, just referenced by different navigational points.

Properties	External Structures	Internal Structures
Based on a timeline	Mostly, yes	Yes

Based on existing structures	Not always	Yes, but can be specific to an individual
Recalled easily	Often used structures are (i.e., ATC calls), but can be difficult to recall, if not structure presented to reference	Yes
Evolves	Mostly unchanged	Yes
Flexible	Not	Yes
Adaptable	Not easily	Yes
Unrestricted	Not	Yes
Based on the flight sequence	Mostly, yes	Yes
Multidimensional	Rarely	Yes

Table 5.10: Information Structure properties

From the data it appears that within the limits of a 'normal' flight the internal information structures are more robust because they rely on an adaptive 'human' system for their maintenance. It appears in the internal structuring of information new information, or a new piece of information, will not be linked to the structure if it does not fit well with the rest of the data. In the example below, the co-pilot receives new instructions from the ATC, but mishears the new heading. The Captain, preoccupied with other tasks, does not hear the ATC instruction. When the co-pilot reads a new heading to be executed, the Captain doubts that the heading is correct, because it does not fit with their previously briefed approach plan. Consider section of the transcript below:

ATC 10:09 M: Call Name 123, we will make you number 3 in the sequence, turn *left heading 045* to intercept the 12 mile arc for 16R ILS.

Co-pilot 10:18 M: *Left heading 060*, to intercept 12 mile arc for ILS 16R, Call Name 123 (reading back to Air Traffic Control)

Co-pilot 10:26 M: *060* (saying to the Captain)

Captain 10:28 M: *I think it was 045* was he or was it us?

Captains comment during a debrief: PNF (i.e. Pilot-Not-Flying, the Co-pilot) misheard what the ATC gave us. He gave us heading 045, but he read, he actually initially give us 060 and then came back again and said left heading 045 and PNF didn't respond and that's when he call him back and said, yep turn left heading 045.

Co-pilot 10:33 M: Sydney, Call Name 123, just confirm that *heading was 060*.

ATC 10:37 M: Call Name 123, negative, *Magnetic 045*.

In the case of the Cali accident (Box 5.2) the crew entered a new navigation point to the

Flight Management System and consequently changed the heading of the aircraft to the wrong direction. The aircraft system accepted that change to the information structure without question. In the example above from the observation study the pilot did not accept similar information, because it did not fit with the rest of the flight plan, i.e., his internal information structure.

CALI AIRCRAFT ACCIDENT (Aeronautica Civil, 1996)

American Airlines Boeing 757-223 was on approach route to the airport in Colombia on 20 December 1995. The approach path was taking place between two mountain ranges. Pilots planned on approach to runway 01. However the runway was changed to 19 and the pilot had to fly a different approach, ROZO 1. This meant changes had to be made in the Flight Management System and a new approach route had to be entered.

To input the new coordinates the pilots had to enter the initial letter of the navigation point and then the system would bring up navigation points that begin with the letter entered. However, there were other navigation points in the area that began with letter 'R'. The pilots selected the navigational point ROMEO, and the autopilot put the aircraft in the left turn. The aircraft shortly after collided with the mountain.

Several events contributed to the crash of Cali flight. Here is list (not exhaustive) of events that lead to the accident.

→ A serious flight delay and pilots fixation on making up time

→ Localized rain, reduced visibility

→ Communication failure between the ATC and the crew

→ The aircraft could not be seen on radar by the ATC

→ Change of runway and lack of time to prepare adequately for a new runway

→ The pilot did not identifying navigational points by their coordinates and did not verify navigational points amongst themselves

→ Poor conventions for navigation data charting

→ Unretracted spoilers during the escape maneuver

Box 5.2: Cali Aircraft Accident Summary

Information structures have a dynamic property, just like the environment that they exist in. The information structures evolve and change and the pilot has to keep up with these changes and new pieces of information that may need to be linked to them. Restructuring or adding information to an existing structure also requires some sort of strategy. From the data it is apparent pilots tend to use a timeline as a baseline for structuring information related to the flight events. Below is the transcript that shows how the pilot builds up the initial structure and then has to change it due to a new runway assignment at the destination airport.

Pilot 09:00 M (debrief pilot comment): 'At this stage all I am doing is just flying Glenfield 1 departure, so all the minor navigation aid selection up there are still the same as what I selected before take off. The only thing that will change, once we get that change of runway. You will see me manipulate that.'

ATC 09:51 M: 'All station in bound Sydney, Sydney terminal information bravo is about to be recorded duty runway 16R (i.e. change of runway), switch now, 140 degrees, 15 knots, QNH 1022.'

Pilot 10:42 M (debrief pilot comment): '…What I did there on the glare shield, the first button press I did, which is just a little back from there, I highlighted one of my pointer selections there, because I knew once the runway has changed I wanted to reference the VOR to give me tracking information & needle pointer around the compass rose on the bottom, but at that point in time we did not have the VOR selected because we had the ILS frequencies in there for runway 07, so I was just waiting for PNF to swope those aids across. Once he did that you saw me there, you saw me there, I selected the VOR to give me some navigation information as to the 12-mile arc intercepting finals for 16R. Around the compass rose there wherever the tale of the pointer is that's where you are. That's the rule you use. Once you've got that you can actually work out heading just by transposing your finger onto that compass card is to where you want to be to intercept a distance or a radial. That's sort of stuff the aircraft can't tell you.'

5.4.1.5 Strategies

So far the data analysis has been considered with regards to the information pilots use; the sources of pilot's information; internal information structures that pilot's use and external information structure that are available to pilots in the environment. While conducting this analysis there are several instances where the pilots were observed employing strategies to assemble, organise, memorise and recall information for the right moment in the flight. Building from the existing data findings this is the point to answer the third posed question, (iii), '*How pilots assemble above collected information to identify aircraft state?*'. Additionally, this question is in line with another question that arose early in the analysis, '*How, and when, do pilots identify the reference for the flight?*'. This latter question is a more detailed version of the initially posed question.

Perhaps the most obvious technique pilots' use for identifying aircraft state information was a *scanning technique*. It was observed that pilots used this routinely to collect and update what they already know about the state of the aircraft. The word "…scan…" appears in pilot's comments over ten times in just a single flight transcript. The pilot uses this technique throughout the flight.

Pilot 04:53 M: All I'm looking for there on the PFD (i.e., Primary Flight Display), now my focus has come in inside once we are far away from the ground. All I am doing is getting my *attitude* and *heading* set on the PFD, so I'm concentrating on *putting the climb-dive marker where I want it*. Obviously we don't have any reference information there now, so I am just looking at the reference, *the pitch ladder*. So that's all. How many degrees I want & I was looking for about *7 degrees nose up* there. That's usually a good figure to remember. As *accelerating* at a nice *rate*, but not to quick, so you are not going to over speed the gear or anything like that. The other part of my **scan** is looking down at the compass card and quickly referencing and having a look at the level on there as to what heading I am flying.

5.4.1.5.1 Scanning Techniques and Referenced Information

The scanning techniques pilots routinely use to identify aircraft state has an affect on their already assembled referenced information. The scanning technique is used throughout the flight at regular time intervals to maintain and to verify aircraft behaviour (see below example Pilot 05:12). In the example the pilot's scans the instruments to maintain the airspeed (i.e., Referenced Information) to avoid stalling the aircraft (i.e., maintain and verify aircraft behaviour).

Pilot 05:12 M: So this is just my side scan there. Looking at the airspeed there, making sure I have enough airspeed there, to sacrifice there, we are not stalling.

Therefore, scanning is a *strategy* involving constantly updating the key *referenced information* to maintain and monitor the appropriate aircraft state throughout the flight. The example below (Pilot 05:49 M) shows how the pilot uses the scanning technique to take in many pieces of information from the instruments.

Pilot 05:49 M: has *to monitor* a lot more… *constantly watching*, if I haven't bust a *height*, an *airspeed* or a *heading* or whatever, so the workload increases significantly…

In the following example (Pilot 16:26 M), whilst in the process of scanning, the pilot explains how he is using this *strategy* to align new information to *referenced information* in order to maintain aircraft track (i.e., direction of travel). This alignment appears similar to aspects, described in the first section of the data analysis, where the pilot is using stationary/unchanging symbols as references to be aligned with another moving symbols to make a complete symbol. In the current case it is deduced that the pilot has a 'mental picture' of how ideally the referenced information should look. The pilot manipulates the aircraft to accomplish the alignment of referenced information to agree with this mental picture. When the references are aligned, this indicates to the pilot that he has accomplished the task successfully. The display features in the diagram below aid the pilot to in using the scanning strategy in the maintenance of the aircraft track. Another similar example, Pilot 13:16 M can been seen in the flight transcript in Appendix 3

Pilot 16: 26 M: So to maintain your track, you need to come left of your heading by 5 degrees and that's what little cross tells you to do. So once *I centralise that bar*, next thing I look for is *getting that cross on the tip of the needle*. Once

I've done that I know that bar is not going to move any more. And that's something I was letting out of my scan.

It was also noted that pilots also employ strategies to construct information before the entire flight, during each briefing, and before each significant part of the flight. Unfortunately, the briefings for the flights were not captured on tape, but copious notes were taken for the purpose of analysis. Before each flight, pilots were given the basic information about the flight including, departure and destination airport by the researcher, then the pilots conducted a full briefing of the flight between themselves. They requested, weather reports for both airports at the corresponding departure and arrival times and ATIS (Automated Terminal Information Service) information containing information about active runway and the type of departure via specific navigation points. They drew the flight on the board, marking and discussing major events, such as, marking any turning points throughout the flight and ATC contact points and discussing any non-flight zones, height, speed and noise restrictions. It appeared that the pilots were mentally registering the sequence and timing of events on the flight route.

From general observations these briefings appear crucial in establishing that the crew are 'on the same page', i.e. their flight plans are aligned/synchronised with each other before they conduct the flight. This is supported by the previous examples from the transcript data above (Co-pilot 10:26 M and Captain 10:28 M). Another good example of this can be seen from the transcript when pilots brief each other about take-off, and the next significant event. From this data it may be deduced that the pilots are constructing and aligning their view on how the flight would proceed from this moment on, by using major references either in the environment or on the displays. The references (i.e., *track 015 and 1TAC or 1000 feet*) are identified and the actions (i.e., *turn right, track 170*) to be executed are associated with these references are stated. For this example further evidence is provided by the pilot's debrief comment stating, '…*by briefing it (i.e., take-off), it's actually putting into, right in to our minds…some of it can be done form memory'*.

Pilot 03:08 M (flight brief): Glenfield 1 departure out of here runway 10; plate stated 4 October 2001, no amendments; gradient required 3.3%, which we can do; *track 015 and 1TAC or 1000 feet*, which ever is later, *turn right, track 170* to intercept 144 for Richmond NDB, track to Glenfield then as cleared.

Pilot 03:08 M (debrief comment on above): 'All that is just interpreting what's on the plate there & *by briefing it, it's actually putting into, right in to our minds*, instead of always refer to it, *some of it can be done from memory*. And usually what I will do with departure, some of the departures would be quite long and complex. However, you really cannot keep all of that information in your head, so what you do is brief the first or you just remember two to three instructions, so like maintain heading 095, 1000 feet or 1 TAC. Next what I'm going to do is turn, right turn on TACAN distance. TACAN is what we use in the military – Tactical Air Navigation, type of DME. 1TAC is one DME essentially, i.e. 1 mile upwind and then make your turn onto 170. They are sort of thing I remember…

A couple of minutes into the flight the pilot recognizes the reference established during the flight brief and commands the associated action (see 05:42).

Pilot 05:42 M (pilot is saying to a co-pilot): *TAC1, turn right 170.*

Pilot 05:42 M (debrief comment on above): So in that, when I said there to myself that was just from memory. *That's what I briefed before we took off.* So *I knew once we got to 1TAC that's what I am going to do*. That takes a little bit of a brain space away of trying to read the next step from your approach plate.

In the example above the pilot used a strategy to help him to recall the required information by constructing *future* references using a *timeline-sequence structure* and later in the flight this reference triggers the recollection of the required action.

Below is an example of pilots briefing each other about 'the approach' and establishing that they are both in agreement about the upcoming event. From this it may be deduced that they were constructing references that would indicate that they are on correct path and where are the locations of the execution points of their next actions (see Co-pilot 11:16 M below). In the example below the reference is an outermarker, when it is reached, indicated by the sound as 'BIP, BIP, BIP' in Morse code, the pilot is satisfied that they are on the right course and it gives him an indication whether they need to make any adjustments.

Co-pilot 11:16 M: 212 NDR MINIMUS radar set to 212. Outermarker check *height 1295 at 4.7* (i.e. distance in miles) I'll give you localiser frequency when you are turning…

Morse code 17:55 M: …BIP, BIP, BIP…

Pilot 17:55 M (debrief comment on above): Right now, I am interested in getting a landing clearance, so I am waiting for that come through. I am also, next thing I'm looking at validating the ILS (i.e. Instrument Landing System) by that outermarker check height again. And *PNF* (i.e. Pilot-Not-Flying, co-pilot) *briefed a little bit before*, as to what the *height, distance we were looking for*, so that's a next step.

5.4.1.5.2 Calculating References

However, not all references that pilots use during flight are necessarily established before the flight or during a briefing. Pilots have strategies to calculate references.

These references generally can be calculated in the same way for any flight. In the transcript below the pilot explained the technique of calculating a '3-degree flight path to the runway, also called a glideslope. The calculations generate points in space that the pilot can later reference to make sure the aircraft is on the required glideslope. The starting point of the glideslope is an important event during last stages of flight. Depending on the terrain, time of the day and weather the correct identification of the starting point of the glideslope along with precise calculations of checkpoints (i.e., references) can be critical.

For the pilot to keep and maintain the 3-degree glideslope requires; first that its starting point is correctly identified, then several references at intervals on the glideslope need to be checked to verify whether he is maintaining the slope all the way to the runway. At example Pilot 14:32 M the pilot explains how he identified the point, '*10 miles out I should be 3000 feet*' where he will start the descent to the runway. The references to check the maintenance of the glideslope is then, for every one mile is a descent of 300 feet, '*at 5 miles out I should be 1 500 feet, 10 miles out I should be 3000 feet*'. At 15:40 the pilot recognises the proximity of the reference, an '*outermarker check-height*', which is '*an intercept… at 10 miles… on glide slope*'. The co-pilot confirms at 15:46. At 15:49 the pilot reaches the top of glideslope and initiates the descent.

Pilot 14:32 M (debrief comment): …And again TACAN means *DME* (i.e. Distance Measuring Equipment), so that I can have *a reference to the outermarker check-height*, when I am likely to incept the glide slope. So things I look for that is, just as a check I always calculate, when I am going to intercept my glide slope, because my style is designed *to enter a 3-degree slope*, you can calculate that *every mile you need to be 300 feet*. So *at 5 miles out I should be 1 500 feet, 10 miles out I should be 3000 feet*. We are *at 3000 feet, so we were going to intercept the glide slope at 10 miles*. So I was just *referencing down to the distance* there at the bottom of the PFD to give me an indication so as to *when I was going to intercept the finals course in the glide slope.*

Pilot 15:40 M: 'We should expect an intercept in about 10 miles, there on the glide slope.'

Co-pilot 15:46 M: 'Quite close in.'

Pilot 15:49 M: 'And leaving 3000 for the minimum of 220.'

Pilot 15:40 M (debrief comment): That's what I was telling you before. I calculated that in my head. Pretty much as you see 10 miles click over, glide slope right in the center. Ready to go.

Numerous calculation techniques are taught to trainee pilots from their very earliest flying experience, which has been primarily experienced by the researcher. These techniques are routinely used by pilots in manual aircraft, and also as a means of cross checking the automation in aircraft with automated systems. Consequently, these techniques are considered important in the analysis. Such calculations often occur when the pilot goes through mental processes to establish references, such as a mental reference for the assessment of when does the pilot need to start levelling off, i.e. a mark at '*10% of your rate of climb*' to the level off altitude. Another mental reference that pilots need to calculate, but is also unavailable on the display in the example below, is a mark on 7 degrees prior the required roll out heading. This is when the pilot will have to begin to come out of a 'banking turn' to 'roll out' on the required heading. The pilot calculates mental references using referenced information, such as '*height… rate of climb…turning rate'*. All the calculations in the given example below are measured in relation to a time, such as a rate of turn in seconds or a rate of climb in minutes.

> Pilot 05:49 M: 'I will just explain something here. That might look like a fairly benign thing. All we are doing there just climbing & turning, but my workload is really increasing there, … *what rate I am climbing at, when I will need to start my level off and also when I will need to start my roll out from a turn. … how many degrees per second I am rolling at; how many feet per minute I am climbing at* … so what I'm looking for. I am having a look at my *rate of climb*. I am doing about 2500 feet/min, so 10% of your rate of climb is what you use to level off at for your *heigh*t so 250 feet before 3000 feet and that's when I've got to start my level off. And they are the things I am thinking about when I am doing that. Obviously approaching about 7 degrees at the *rate I was turning at* – rate 1 (i.e. 3 degrees per second or turn at the rate 1 is when the aircraft turns full 360 degrees in two minutes), is when you start your roll out.
>
> Ye, looks simple, but that what we do a lot of practice for instrument flying, doing coordination exercises, turning and climbing at the same time, descending…'.

All references in the above example are against a scale. The position on that scale gives an established reference a significant and a meaningful point relative to a new reference to the pilot. In the above calculation, the pilot uses three different scales; the altitude scale in feet and in minutes; the compass gradation in degrees, and the time in minutes and seconds. For example, in calculations to make the correct 'roll out' on a heading, the pilot uses two references; one existing reference on the compass gradation scale (i.e., the heading), and a new reference he has calculated to assist him to begin the rollout (e.g. in this case 7 degrees prior to the required heading). Therefore, it can be seen that once the pilot has established references they are meaningless unless they are represented *on some kind of scale* and *relative to* another reference.

The same is true with other references that pilots use. From the analysis it appears that references have to be used; either in relation to other features (i.e. display features, wing symbols); against other references, and when assessed against one another, each reference be at the appropriate scale. In the example below (Pilot 20:12 M), the pilot talks about navigational aids, i.e., outside physical references, as points of reference to help him in a strategy to maintain course. Here, the pilot uses navigation aids as references to compare his position relative to them, to establish the position of aircraft, and identify the next point of an event, such as 'level off' or turn.

> Pilot 20:12 M: …margins you have to anticipate – level off, turning on heading. That sort of thing. Manually thinking, *where you are with regards to navigation aids* and just things like that increase the workload slightly.

Re-examining the flight as a whole, it can be seen that, calculated references and established references (e.g. navigational aids), all become a part of the flight path. The references are effectively *'strung together'* to construct a desired flight path, where references exist to mark a point of execution or completion of the next action, as discussed in strategies earlier. However, the references used in strategies are not only calculated, or established during a brief (e.g. a navigational point), but they also come from previous experience, such as described in the subsequent example.

The comment below shows that the pilot knew *from previous experience*, not just from the earlier briefing, that they are approaching a significant point on the flight path, i.e., a reference initiating the start of a descent where ATC would contact them shortly. From the researchers previous flight experience it appears that 'flight stages' are a fundamental concept of flight training. Flight stages are important points that all flights have, i.e.; taxi, take-off, climb, top of climb, cruise, top of descent, descent, approach, final, landing and taxi. Reviewing the data, flight stages are evident in all the flights. Considering the flight stages concept, it is reasonable here to deduce that the pilot had a *plan of sequenced events/stages of flight for the entire flight* and was '*expecting* (a command to descent to a specific height) *to come up*'.

> ATC 12:52 M: 'Call Name 123 descent to 3000.'
>
> Pilot 12:54 M: '3000, left 5000. Call Name 123'
>
> Pilot 12:54 M: The ATC gave us descend down to 3000, which is the starting height from which you make the approach, so that's something *we were expecting* to come up soon anyway.

5.4.1.5.3 'Backbone' Strategy

Another aspect that arises from the data is that pilots also have strategies to *adapt* to *changes* in the flight plan. Scrutinising data around changes to the flight plan in the observed study shows that, the pilot used the most *stationary/unchanging reference* of the flight as a 'backbone' or *'stationary reference'*, such as flight stages. It is reasoned that pilots use the flight stages as a *stationary reference* as this is very unlikely to change. Using the flight plan as a *stationary reference* provides a structure onto which 'less stationary' or *interchangeable references*, i.e., the airport of departure, route via a specific navigation aid/point, further navigation aids and associated headings, approach route, planned runway and destination airport can be assigned. These *interchangeable references* then hold variable, or *dynamic references*, such as height, speed and airspace restrictions. When a change to an element of the flight plan occurs the pilot only needs to address and then change minor points, using this hierarchy. The example below (Pilot 09:00 M) shows this in action as change of runway that is about to take place.

Pilot 09:00 M: 'At this stage all I am doing is just flying Glenfield 1 departure, so all the minor navigation aid selection up there are still the same as what I selected before take off. The only thing that will change, once we get that change of runway. You will see me manipulate that.'

5.4.1.5.4 Mental Extrapolation Strategy

One more strategy that is vital to mention, are pilots' meticulous considerations of future outcomes. Pilots throughout the flight perform mental extrapolations of future outcomes based on current observable and known parameters. Similar to the example below, the pilot considers the result of staying on the selected course, which he thinks was commanded by the Air Traffic Control. When the pilot mentally puts on the navigational display the extrapolated path based on current trajectory, he notices that this will take them off required course and will not bring them to the next point in space.

The use of this strategy is always necessary to cross check aircraft systems performance and execution of navigational plan. In the case below the use of the mental extrapolation strategy helped the pilot to identify the course entry error, that was initially mishear and incorrectly entered by the crew.

Co-Pilot 10:33 M: 'Sydney, Treasure 123, just confirm that heading was 060.'

Pilot 10:33 M (debrief comment): 'PNF misheard what the ATC gave us. He gave us heading 045, but he read, he actually initially give us 060 & then came back again & said left heading 045 & PNF didn't respond & that's when he call him back & said, yep turn left heading 045.'

ATC 10:37 M: 'Treasure 123, negative, Magnetic 045.'

Co-Pilot 10:41 M: '045, Treasure 123.'

Pilot 10:42 M (debrief comment): 'And the reason I query that is because I had a look at the compass rose there & thought that 060 is gonna put us fairly close to the finals course there, by the time we intercept the 12 mile arc, so I thought we really need to come further left there. And that sounds reasonable to me, so I better check & that just worked out that it was what he said anyway.'

The mental extrapolation strategy helps pilot identify the onset of navigational errors and system performance. This also helps pilots to monitor automation performance and provide pilots with ample time to correct undesired flight outcomes.

The preceding examples are taken from the analysis of a manual flight that represents one-eighths of the empirical data. This flight is used as it is both: representative of the findings for the manually operated aircraft and examples from the single flight provide an element of continuity to the narrative of the chapter. The discussion part of this chapter includes the results of the same data analysis on the rest of the data, i.e., three more manual flights and four automated flights.

5.4.2 Data analysis – automated aircraft operation

The analysis of automated flight was conducted using the same evolutionary four-stage cycle. The results of the analysis are similar to those of the manual flight data analysis. The only differences occur in some of the structure of information and that Standard Operating Procedure is extended to include activation of automated functions. The discussion part of the chapter includes the results of both automated and manual flight operation. The differences are highlighted.

One significant point to note here is that, in observing the comparison of pilot activity between automated and non-automated aircraft, the pilots appeared similarly occupied. Additionally, the strategies and references that the pilots were observed using were the same in both types of aircraft operation, with the difference that the calculation of references that pilots would later use in flight is done by automation in the automated aircraft. However, pilots do crosscheck all the data against the charts and their manual calculations before the flight, even for the automated flight, as in the example below (Pilot 04:00 A).

Pilot 04:00 A: '*Checking* the Take-off and landing data is correct. You might actually see me flip trough my book see if my Take-off and landing data, check the speeds, for what weight we are at and that way it's *checking the calculation* of the CNI (i.e. Communications, Navigation, and Identification Management Unit) to insure that's correct. Then I will *check the route* that we have, put in the box and that way we *check that against our navigational charts* to make sure that distances and tracks we have on those match up to what the COMM/NAV (i.e. Communication and Navigation) interface gives us. That way we will know when we engage the automation will give us the correct path for us.

…The landing data includes threshold speeds and approach speeds per flap setting. So if I was with 0 (zero) flap there will an approach speed and a threshold speed and what I will be looking at for are those on finals is to try and aim to hit *those speeds* (i.e. Behavior reference). The *approach speed* (i.e. Behavior reference) I will fly all the down until I get close to *the threshold* (i.e. Environment reference) and then I pull a little bit of power off, have the speed dribble back until I hit *my threshold speed* (Behavior reference) over *the threshold 350 feet* (i.e. Environment reference); and then from there I pull my throttles back to flight idle and speed will decay to *a touch down speed* (i.e. Behavior reference). *Those speeds are already pre-calculated in the CNI and by me doing it I'm checking that they are correct*, if they are not correct, we are possibly flying slower then we are required to be for that weight.

The above example also illustrates that pilots use the same information for references, such as speed and height references, in the automated flight as they do during a manual flight.

An example of automation failure, which was not planned, is worth mentioning here. The Integrated Navigation (INAV) failed and pilots lost navigation support on the display. This was a good example to observe how pilots coped when the automation failed to provide the required reference information (see Pilot 16:51 A). In this example the pilot is calculating the required references with the help of the following; a 'heading bug' (a manually set indicator concentric with the dial), the dial needle, and his recollections of information he acquired before the flight (see Pilot 17:36 A).

Pilot 16:51 A: 'For some reason my INAV posses, 'stuffing up' (i.e. not working properly).'

Pilot 17:36 A: (debrief comment): Flight Director is not doing anything for me apart from keeping me on heading. But what I'm doing, which (Flight Director heading) I just selected. *I had to manually think* of: 'I'm coming around to this radial, there is 2 degrees lead on the NDB (i.e. Nondirectional Beacon) now, because we are about 20 miles away from it, therefore if I turn now, I'm gonna roll out on the heading inbound to the Glenfield NDB of 144. That's *the calculation I'm doing mentally*. And all I'm doing is manipulating the *heading bug* to give me what I want from *that needle*, but the Flight Director is not helping me.''

Researcher: Where did you acquire the distance that you just calculated?

Pilot: I didn't (…acquire that information…). *I knew, because I looked on the chart before we left.* It's about 25 miles is the profile between the Glenfield NDB and Richmond. And I know we hadn't been flying for more then 2 or 3 minutes at that stage so we gain 5 miles or 10 miles may be, so we still had 15 to 20 track miles to the NDB to go and that's just a piloting skill. That's what you keep in the back of your mind I guess. That's what good about NAV/RADAR (i.e. Navigation and Radar) display because *of the range ring* on it as well.

The last comment from the pilot illustrates how the pilot strung and structured, information together when it was not available from the automated display. Here, the pilot uses *the range rings,* the distance between which corresponds to a pilot selectable distance. These concentric rings were then used by the pilot as a reference for distance to estimate the aircraft's position relative to both, the departure and destination runways. The pilot also used time, as another reference for the distance travelled, by calculating the distance travelling in each minute. The pilot used both references in combination to establish accurately his position relative both departure and destination airports.

It can be seen from the last debrief comment that pilots use the same references, strategies and structures either, when automation fails, or to 'double check' that the automation has given them the correct information. During automated flights pilots appeared to have used more often a *monitoring strategy*, which consisted of the pilots' knowing in the first instance what to expect, or '*look for, watch for*' in specific references and trends. The references were either selected on the display or pre-calculated mentally. Therefore, the trend, appearing on the display needs to be initially *'visualised'* in the pilot's mind, in order that the actual reference confirms his expectations of the aircraft's behaviour. See the comment below as an illustration of this argument (see Pilot comment 29:54).

> Pilot 29:54 A: 'You can hear the beacon coming through … the outer marker, which is that sound. All it is just *a radio beacon underneath* (i.e. Environment reference) and that particular point, *at that distance from the runway* (i.e. *relative to* another Environment reference) that give us an accurate check at 1295 feet (i.e. Environment reference), that we are right on the glideslope. It validates the landing instrument system for us (i.e. double check) and by us checking we know that the glideslope is good and it checks out and then *I look* at the Primary Flight Display then and *make sure* the glideslope indicator is right on the center.'

In the above example the pilot had already mentally assigned a position for the glideslope indicator on the display and that is where he is *looking for* it, to confirm the position of it is where he expects it. This strategy of expecting, and then looking for 'IT' (i.e., the reference - the 'picture' in the pilot's mind), is used frequently by pilots throughout the entire automated flight. The same was observed in manual flights, but because pilots had instantaneous manual control of almost all of the aircraft's performance, pilots' expectation and monitoring behaviour was seen less frequently.

It was observed that some of the information structures provided by the automation create confusion, and it is argued that this is because they are not solely based on the information structures pilots use already. One example observed was structure of information in the Communications, Navigation, and Identification Management Unit (CNI-MU). The structure of the CNI-MU does not follow any of the structures pilots' use as deduced from the analysis, or indeed, any from already established aircraft instrumentation. During the observations pilots had difficulty finding, and so questioned, the location of a specific 'pages' of information in the CNI-MU. The immediate location of system pages in the CNI-MU can be crucial, especially in change of runway situation, where access to the right page is required to change the required navigation data.

Moreover, the structure of the page changes as the flight progresses. For example, different pages come up if the system is accessed in the air or on the ground. One example of page structure change is when the aircraft is powered up, at this point the initiation page would comes up. However, this page cannot be brought up later in the flight, and the information initially entered on this page is distributed through other pages. This was observed to cause confusion, and made it difficult for pilots to learn the structure of information in the CNI-MU while operating the aircraft.

Last, but not least, of the important results from the automated flights was the confusion pilots have with applied the *philosophy* of automation presentation. The instrument symbols in the manual aircraft represent the actual position of the aircraft in relation to all other symbology. However, during the automated flight, the information is presented as means to guide the pilot on the correct path. The *philosophy* of the automated information presentation is '*Fly to*', or '*Fly towards*', meaning if the pilot follows the symbol it will lead him/her on the correct path. This means that the same information will be presented differently in the manual and automated aircraft. For example, during manual flight the pilot would see the symbol *above one symbol*, where during the automated flight the pilots would see the symbol *below one symbol*.

Confusion of this nature is exactly what happened during the observed flights where, in one instance, one of the experienced pilots confused such an annunciation on the Primary Flight Display (see below: Pilot 31:19 A). Observation of pilot training, and the study of aircraft operation manuals reinforced that the philosophy of 'Fly towards', when applied to cockpit design, actually contradicts what pilots' are familiar with when the automation is not engaged.

> Pilot 31:19 A: Just glancing on the Primary Flight Display there, just to make sure that everything is still right. Can see that I'm relatively on glideslope, just a little bit *above*, actually just a little *below*, because *it's fly to* (i.e. the pilot is referring to the philosophy of design).'

5.4.3 Data analysis prior to the observation flight and during training

In preparation for the flight:

At the beginning of the analysis of the master tape footage the pilot is requested to recall their actual observations on the flightdeck. The pilot then gives distinct consideration to their *preparation* for the flight and their setting of *things right.* At this point the pilot is aligning existing visual references in the cockpit to their '*accustomed to*' position.

These preparations proceed in a set order, first, before aircraft power up, the pilot adjusts his seat height and its proximity to the pedals. This may appear trivial, however, it accomplishes a number of key ergonomic requirements, such as physical comfort (vital for a long flight), that all the dials on the overhead panel are within adequate reach, that he is positioned close enough to the radar/brake pedals, and also that he is high enough to see over the instrument panel ahead. The latter is of key importance as it forms the primary resource for the future alignment of visual references and their relative position to the outside references, such as the horizon. The pilot's visual perspective from his seat carries implications on how references are aligned, and how the pilot perceives the information in the environment outside the aircraft (i.e., a view over the instrument panel), where the top of the panel acts as a *'relative to'* reference to the outside reference (e.g., the runway view on approach).

The pilot's eye-level position over the instrument panel, becomes important when the pilot has to fly without constantly referring to the instruments that indicate his position *relative to* the horizon, i.e., nose up, nose down, or when turning right or left. If there is good visibility the pilot constantly refers to both the outside horizon and the instruments while turning or climbing to check for four unwanted effects: over or under 'banking' the aircraft, and too great or too small 'climb' or 'dive'. This can happen due to a lag in instrument readings (both manual and automated) that interpret the aircraft position. The lag in the instrument readings makes the pilot '*chase*', as it commonly referred to, the intended position. To avoid the *chase* the pilot should learn to keep a constant angle between the top of the instrument panel *relative to* outside references, such as, the horizon in the desired bank angle, climb or decent, and then maintain that position during the manoeuvre.

The pilot's review of the flight deck and these aspects reminded the researcher of similar experiences during pilot training where the instructor insisted on correct seat adjustments before each flight so that eye-level over the instrument panel was the same on every flight.

This eye-level position *relative to* the view over the instrument panel is also important during the approach and landing flight phase. The pilot's eye-level needs to be in its required and accustomed position for the pilot to place *relative to* references against the top of instrument panel. If the pilot has too high, or too low, an eye-level position the implication would be either too high or low angle of attack during a descent. This effect is due to the relative distance between the top of the instrument panel and the horizon. A similar effect can be seen in the example from the pilot's comment from the automated flight below (Pilot: 30:19 A). In this example the pilot finds it important, and helpful, to establish his references from the outside environment relative to the window frame of the cockpit

> Pilot: 30:19 A: 'Now what I'm trying to do is *to establish the frame of reference within that window*, where the runway is, what my instruments are telling me, so that I can... if you've been starring inside and when they finally look outside and that's when you got to flare and land, it doesn't give you enough time to adjust to a new visual environment. So I'm trying to establish the visual environment again and get my eye in for where I'm aiming on the runway.

Reviewing the data analysis of this section in completion, it appears that all the information pilots used was connected, either relative to another reference (i.e., instrument reading), or relative to an external reference (e.g. the horizon, relative to the top of the instrument panel). The information pilots used were constantly evolving, but *relative to* references were used to maintain a steady flight path. In the next section, the discussion – in retrospect of data analysis, the spiral analysis shows of how pilots acquire and use information, how information evolves and how pieces of information relate to each other.

The analysis used in this thesis can be described as similar to tracing a web of information and no matter where the researcher starts until he/she runs through most of the routes that make the picture complete the analysis is not finished. There may be gaps where information is missing, but these gaps will be filled when designing an information display for a specific task in the same domain. However, despite the gaps if there are all links present and complete, there are no missing links in extracted data.

5.5 In Retrospect of data analysis…

As the analysis progressed the diagram of how pilots use information began to emerge. This emerging diagram is based on the four-stage iterative analysis progression (Figure 5.10) used in the data analysis. Both the data analysis diagrams, and pilot information use diagram, are concerned with information collection, analysis and use. The pilot information diagram required intermediate stages to explain in detail how information evolved before, during and after the flight. The resulting diagram has an octagon shape representing eight stages of pilot information use. The octagon diagram evolves into a spiral at each progression through eight stages, representing pilot's progression in acquiring information for the flight, knowledge and experience.

The first stage of the information progression represents the pilot's existing experience based knowledge. Such knowledge includes: the stages that each flight consists of, the structure of information, (e.g. Air Traffic Control calls and flight briefs), and the strategies that the pilot has acquired through training and 'on-line' operation. This stage would also include a request for a new flight, which will build on existing knowledge and experience. The request itself will create the movement into the second stage.

The second stage represents the acquisition of all new information related to the flight. All information regarding this flight will be introduced during this stage, the brief, the planning of the route, and route related weather and restrictions. The second stage is also the beginning of information acquisition and the processing of new information that lasts four stages.

The third stage of information acquisition involves identifying for transpired alternative airports and all the related information to alternative arrangements required for the flight, such additional route calculations, relevant weather and restrictions for the alternative destination. New regulations that are relevant or have been introduced will also be introduced in this stage.

Stage four is the 'selector' of information acquisition, where new solutions are identified, and where separation of work, tasks and problems are assigned. This stage is where new information is generated from all the acquired information and from the pre-existing knowledge of the pilot. The calculation of relevant flight references also occurs at this stage. If this stage were associated with a flight stage, it would be a brief before take-off, or a brief before a significant event or a brief due to a change in original flight plan.

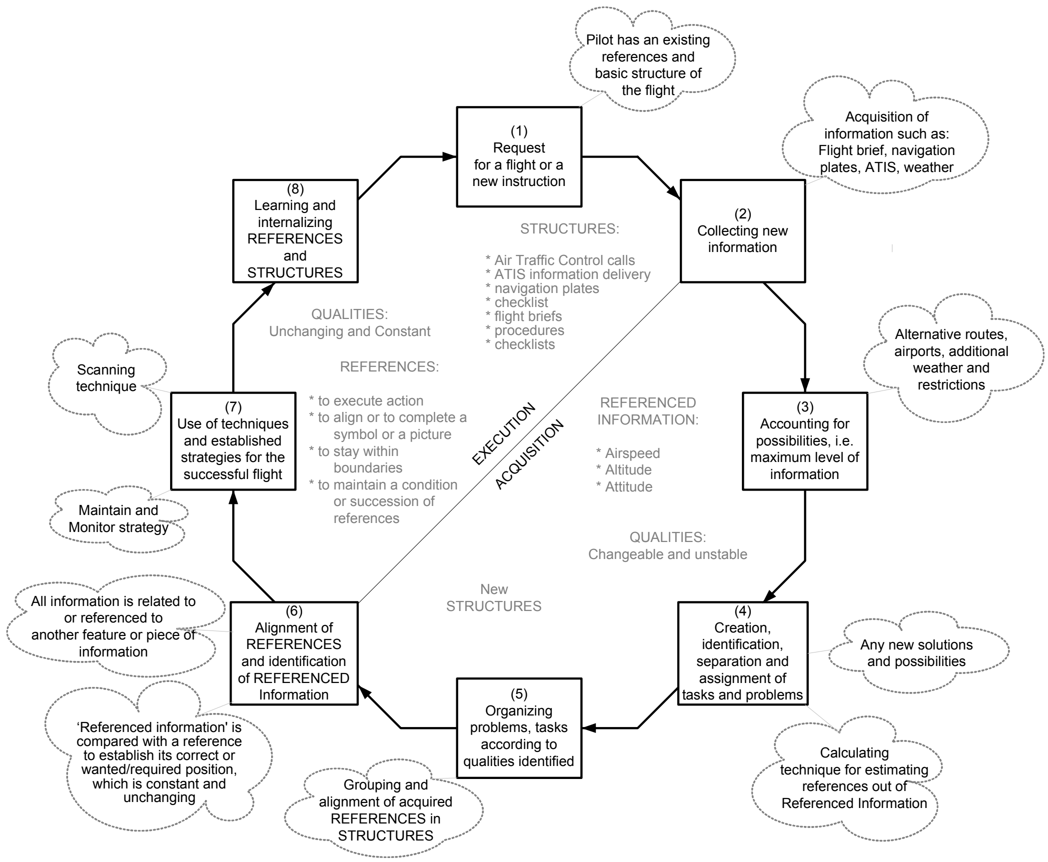


Figure 5.10: Evolution of Information Flow

Stage five involves organising information. This is where pilots group and align references that they later used in flight. At this stage the information becomes sorted in structures to assist pilots in implementation of strategies.

Stage six is the end of information acquisition and the beginning of information use and the flight execution stage. All newly acquired information references and information structures are compared with existing references and structures. This stage then holds the outcome of these comparisons. Additionally, all information is connected and information dependencies and links are established. Consequently, information references find their relative position on the display, relative to each other, or relative to already existing references. This is the point of clarity. At this stage the information is not likely to change its position, unless a change in flight plan or situation occurs.

Flight execution happens at stage seven. All the strategies, i.e., maintain, monitor and scan, extrapolate, that pilots use to fly the aircraft are implemented here, on the basis of the information collected from previous experience and newly acquired and organised information.

Stage eight involves turning all newly attained information, such as references and structures, in to knowledge and experience. The cycle then spirals on to a new level at this stage, the pilot having attained additional knowledge and experience. The new cycles is triggered by a new flight or a change to flight plan.

5.5.1 What is reference and how is it used?

References possess specific properties. They are constant, reliable and unchanging. This can be distinguishes them from other information and so makes them good pieces of information to rely on. For example, references would remain in a specific location or maintain their shape, size, or weight. Consequently, these can be used to compare them to other objects or pieces of information to establish their relative position or to represent a new piece of information or object. However, a reference on its own has no meaning. The reference is usually established among a large amount of information to differentiate the 'value' of the information that is required. The reference would show where a person or navigation appoint is in relation to a bigger picture, a map of a town, or a position in the airport. This makes a reference reliable to mark the onset of another event, for example a 'level off point' would be a reference in space and time.

Every reference pilot use has a connection either to previous references in time and space or is relative to other internal or external type of reference. The pilot needs a reference system that is connected in order to be able to trace information throughout the flight. The pilot ties the information together using references alignment, to keep continuation of information. This also helps the pilots to retain and recall information.

References either can already exist in the environment, or on the display, and these are visible references that pilots use to establish the relative position of other symbols or features. References can also exist in the pilot's mind. These types of references can either be professionally acquired, such as during the basic flight stages of the any flight, or acquired through common human life experience, not necessarily related to professional experience. These 'human references' are common or recognisable to humans, such as horizon, which in common experience has the properties of being constant and unchanging. The table below shows four groups of references and their source (Table 5.11).

HUMAN or PROFESSIONAL References	**EXTERNAL**	**INTERNAL**
EXISTING	The reference that exists outside and is visible against which other visible objects can be compared to or related to, such as the Horizon	The reference is a construction that exists in person's mind. This reference is not always obtained through external visual representation; for example, representation of Time as a picture or as a moment i.e., a minute or a week, but it also can be a face of a clock for a position representation of 3 or 11

		o'clock.
ACQUIRED	These references can already exist in the environment, but they are recently acquired, but new to the person, for example navigation points or significant buildings in town. These references can either be created by the pilot or a person to accomplish the work required, such as glideslope check points in space and later can become internal if they are used frequently. →	The reference has been acquired through experience professional or human/personal and have been internalised to have a presentation, for example basic flight stages would be such a references for pilots

Table 5.11: Type of References

Based on the data analysis, the references pilots used can be further distinguished in to three categories (Table 5.12). The second to top horizontal row divides references in to three columns, corresponding to types of references; physical description, appearance, behaviour related and environment related references. The third row provides the description of each reference category.

REFERENCES for		
Physical description/appearance	**Behaviour**	**Environment**
Reference representing a physical constraint, this will also include a constraint in the environment, such as a runway length for example	*Reference either representing current or future behaviour or the limitations of the behaviour/performance*	*Reference established in the environment, either has to be maintained or signify the next event*
Flap 50 position	Flying straight (heading 015)	1000 feet
Landing gear down or up	Turning at rate 1 (i.e., 3 degrees per second)	Glideslope: 10 miles out at 3000 feet and 5 miles out at 1 500 feet
Fuel level	Climb at 7 degrees	Outermarker (navigation point)
Engine power level	Climb at 2500 feet per minute	Cloud base at 1500 feet
Trim of the aircraft	Airspeed of 120 knots	12 mile arc

Table 5.12: Description and examples of references in three categories

Within the table the references are not necessarily compared only to each other within the category. For example, on the navigation display the environment reference, such a navigation point ROMEO, can be compared against the behavioural reference, marked on the compass card as a heading, to establish whether the aircraft is on the correct course.

Different category references can also be connected to indicate that an event, for example, the environment reference (i.e., 1000 feet), can be the trigger for a behavioural reference to be executed or maintained (i.e., 60 degree bank). The pilot connects references, not only in previously reported structures, but also from alternate behaviour, the environment and physical references, in order to execute of the flight plan. One further example is given below (Pilot 14:39 M) of two references that through their connection and alternation trigger an action. In this example on reaching a speed of 180, is recognised as a safe speed to reconfigure the physical structure of the aircraft, by lowering flaps to 50.

> Pilot 14:39 M: '…Below 180, flaps 50.'

References can be used, and are used by pilots, to mark present and future events. All references in Table 5.12, above, can, for example, mark current position and identifying future position of the aircraft against a new altitude reference. To identify present from future, or even past references, pilots use structures that align references relative to each other, or along an established parameter, such as distance and time.

The references used by pilots on automated flights did not significantly vary from those used in the manual flights. Automation modes represent aircraft behaviour references, for example a 'VS –2000', represents the aircraft descending at 2000 feet per minute. One further example of combined references involves use of the Flight Director. Flight Director is an aspect of automation combines several references in to one, with the aim to ease pilots workload. The example below (Pilot 05:49 M) shows a pilot's comments on the Flight Director:

> Pilot 05:49 M: Like the Flight Director works out what *rate I am climbing* at (i.e. Behavior reference), *when I will need to start my level off* (i.e. Environment reference) and also *when I will need to start my roll out* (Environment reference) from a turn. It calculates *how many degrees per second I am rolling at* (i.e. Behavior reference); *how many feet per minute I am climbing at* (i.e. Behavior reference) and gives me a nice solution there, so that ball eventually just comes down on to the horizon and smack-bang on my heading.

One of many fascinating strategies that were observed in relation to references is that pilots' appear to know what they are *looking for* at all times. Further, the pilot appears to know what to expect on the display, or in the response of the aircraft to the environmental or to physical changes. The pilot's were observed to look for these trends and changes to appear as references on their displays at specific instances. From these observations it was determined that the pilots always appeared 'mentally' ahead of the aircraft's current situation, and so their expectation and monitoring strategies are deduced as them waiting for the actual events to catch up with their 'mental movie/picture' of *how the events should evolve.* An example of this is given below (Pilot 19:33 A).

> Pilot 19:33 A: …and the next thing I was looking at once I've made that speed change to 210, I was looking for that the speed tape was increasing…

It was observed that when the expected references are not reached, or missed, the pilot questions what has happened, or what has influenced the resulting aircraft behaviour.

Lastly, references also can be identified due to the context they are used in, even when full information is not given about them. For example, when ATIS information was read to the pilot, the Air Traffic Control mentioned only numbers, but because the number in that information structure can only represent the wind direction, i.e., '*140 degrees, 15 knots'*, see below (ATC 09:51 M).

> ATC 09:51 M: 'All station in bound Sydney, Sydney terminal information bravo is about to be recorded duty runway 16R, switch now, *140 degrees, 15 knots*, QNH 1022.'

In the case above, although the information was not complete, the context of where the reference was used and the structure of the information gave definite clues to the pilots to what the Air Traffic Control was referring too.

Comparing the physical actions of pilots on both the manual and automated flights it appeared that they were similarly busy. The amount of time it took pilots on the automated flight, in setting references in to the automated systems, appeared to correspond well with the time taken to pilot the aircraft manually. The pilot's debrief comments, below, provide some detail about how the pilot attempted to use the automation to reduce his workload. In the example it shows how the pilot offloaded all the references he needed to hold in his own memory to the automation, so the automation could then follow the references and this meant that he now only needed to check that the references were correct, and that the resulting aircraft configuration, behaviour and flight path matched the flight plan in his mind. For a long flight offloading the basic flying to the aircraft, can put less strain on the pilot. However, on a short flight this automation can be counterproductive, as it commonly entails the pilot programming and reprogramming the automation. The pilot notes this in the debrief comment below (comment Pilot 21:52 A).

> Pilot 21:52 A (debrief comment): …I'm going: '*How am I going to intercept 12 mile arc*, when *I don't have the VOR needle up'*, because *we have selected the ILS frequencies in there.* You saw me glancing across the NAV radar display there. I've already had a look at the range rings there, when we got that radar vectored heading …that increases our workload even more, because now I've got to think about getting us back on track before we can start the approach.

So I'm looking at distance and then I'm thinking at what distance do I want to turn to incept the arc to get back on profile again to where I can intercept finals.

Researcher : … and all of that you are thinking in your head?

Pilot (debrief comment): Yes, the *Flight Director can't help me, because the ILS is selected up there* at the moment.'

Researcher : … you can't change that?

Pilot (debrief comment): *We could change that, but it would be more work for us* to seat down or to look into the CNI quickly change the VOR needles and then by the time… The other thing I was thinking, we are very close to the finals course, but the time we select the VOR needles up, I will be on my 12 mile arc and then all over sudden we've got to select the ILS frequency again anyway. So that the CDI bar is going to give me information on the intercepting the finals course. So it wasn't worthwhile changing over for that long, it would have increased our workload more. So what I'm looking at is the distance on the bottom of the PFD there and working out at what distance I have to turn into the 12 mile arc.

5.5.2 What are the Structures?

One of the several outcomes of this study is that the analysis of the data helped to preserve the dynamics of the environment that pilots operate in. This preservation enabled many findings about the structuring of information to emerge. Earlier, it was discussed that the evolution of information appears to occur in a spiral manner, before, after, and throughout the flight. Additionally, it was found that there are stationary structures (i.e., the basic flight phases) that never change and serve as a 'backbone' for more interchangeable structures (i.e., such as flight plan and route), which can change at any moment. However, given that both stationary and interchangeable structures co-exist the flow and exchange of dynamic information (i.e., altitude, route and heading) must be ordered so that this can proceed without creating chaos in the information structure.

All the pre-existing information structures have evolved over the relatively short period of aviation development, roughly 100 years. These include the information structures such as; ATC calls, ATIS information delivery, navigation plates, flight checklist, flight briefs and procedures. All these information structures have developed both, through pre-considered design, but also through trial and error. This has resulted in robust information structures that appear very suited to the event they order. For example, the flight checklist is performed in the order that the actions should be executed during the flight; flight briefings of the entire flight are similarly ordered, with the flight stages briefed in order also. Additionally, the ATC calls have a structure suitable for audio information, where the first sentence addresses the attention of the appropriate crew, and then their instructions follow. Also, in a pilot response call, to compensate for humans relatively poor ability to memorise, the pilot first reads the instruction that the crew just received and lastly repeats their 'call name'. History documents it took a lot of thought, trial and error and lives to establish these effective in human-machine operation information structures in this domain (for examples see (Billings, 1997) and (Garland, Wise, & Hopkin, 1999).

Without performing the detailed analysis it is not apparent just how large an amount of information pilots' have to deal with through their senses in flight. Using the results of this study may assist in structuring information to support pilots' workflow. Information structure can be supported through interface, and cockpit design. If implemented in the correct manner this may help pilots use information more efficiently as the information will be presented in familiar structures, at the appropriate instances seemingly fluidly as they conduct the flight.

During the preliminary study it was established that pilots use virtually the same information about the future and the present aircraft states. The same was confirmed during this study. However, as it was noted during the observation of training, and confirmed in this study, current displays do not have much information to facilitate pilots need to plan ahead for each manoeuvre, and so 'stay ahead of the aircraft' or see the immediate and future effects of the aircraft's current configuration.

Current displays also provide minimal to no time related information, which as it was observed plays a crucial role in monitoring aircraft performance and behaviour. Seeing the effects of the aircraft's current configuration and behaviour will support the pilot's need be ahead of the aircraft. The pilot may then be able to recognise potential problems early, and so may be able to take corrective action, or even preventative actions prior to the activation, or just upon an activation of an automation mode.

5.6 CONCLUSION

An important finding from this data analysis is that pilots' already have existing information structures and pieces of information that are significant to them. These information structures and strategies have been developing and evolving over a 100 years of iterations. There are apparently fundamental reasons behind the fact that even recent automation has not greatly influenced, and in fact, has not greatly changed the way pilots use information, as it was observed in this study. It would appear timely to use the results of this study, on how pilots use the information (i.e., references), structures and strategies, to inform and support designers and engineers of the new generation of automated glass cockpit information space.

The results of this study also confirms initial assumptions made in the observation of the pilots in training and operating on-line, that pilots attempt to use the same strategies, and apply the same rules, that they are familiar with in both manual and automated aircraft. This study shows problems occur when automated interfaces present familiar information to pilots' in a different manner to the pilot's expectations of that information's structure. This especially apparent in relative to visual references where conventions are effectively reversed in the manual and automated aircraft. These findings may also represent part of the explanation in previously conducted studies (Sarter & Woods, 1992; 1994; 1995), where pilots were surprised by automation response/behaviour.

The root cause of pilots' misunderstandings with automation presentation appears to be in assumptions and grounding of information structure philosophy on which the design of displays and the cockpit information layout are based.

5.6.1 Lead to chapter 6 and the Experiment

It appears an interesting finding that pre-existing common, or everyday 'human experience' feature in the pilots' information structures and strategies. From this finding it appears that there is possible further work that could be done to elicit more apparently familiar information structures appropriate for aerospace from everyday experience. The next chapter will focus on the review of existing theories of how we use similar information in everyday life and concluded with how it is applicable in design of the aircraft displays.

Humans have a natural ability, and practice lifelong, comparing and estimating instead of measuring and doing time-consuming, not always necessary, calculation. Estimating saves us time and cognitive effort, when other important tasks have to be attended to. Pilots have to perform constant and vital calculations to monitor and estimate aircraft performance. For example, by using our natural ability to compare two parameters on a display, rather than by relying on the need to perform a two-step calculation (i.e., 1. target altitude minus current altitude; 2. altitude to climb/descent divided by current vertical speed equals time to altitude), pilots' workflow may be assisted by saving them time and cognitive effort. This discussed further in Chapters six and seven.

Chapter 6: Mind Reference Framework

6.1 Introduction

This chapter aims to bring the results of all three studies: the preliminary (chapter 3), the observation study of training (including the description of existing problems in the cockpit (chapter 4), and the empirical study (chapter 5) together in a coherent manner, making a statement about how pilots use information. Existing theories will then be considered to establish the grounding of the statement with a proposal of using these assumptions in design of information space in a glass cockpit.

6.2 Bringing results together

In chapter 4 it was established that pilots have problems understanding and using information on three levels: perceptual, contextual and semantic. The *Perceptual level* is concerned with visual representation of information on the display. The *Contextual level* is concerned with interpretation of information according to both its situation of presentation and its surrounding conditions. The *Semantic level* deals with the meaning behind the information that is available for pilots' to interpret.

All of the problems concerning understanding of information in the cockpit, whether *perceptual*, *contextual* or *semantic* were related to information about either the state of the aircraft, the behaviour it was exhibiting, or about to exhibit under specific conditions in the surrounding environment. In the preceding chapters four and five, where the results of the empirical study were discussed, it appeared that pilots also used specific pieces of information that can be classified in the same three categories: *physical* (i.e., aircraft state), *behavioural* and *environmental*.

However, the three information categories (i.e., physical, behavioural and environmental) discussed in chapters four and five have different properties. The properties of information discussed in chapter four were related to pilots experiencing problems using information, such as understanding the current aircraft configuration (i.e., *physical*), aircraft *behaviour* and aircraft position in the *environment*, as well as understanding the effects from the environment either on the aircraft state or behaviour. The properties of information discussed in chapter five dealt with how pilots made sense of information in flight operation. Figure 6.1 below shows the how pilots' assembled such information. Information on the left side of the figure shows how information is spread out in the operating environment. The information on right side of the figure shows how pilots organise this information into usable structures in order to operate the aircraft effectively.

The stars in the figure 6.1 below symbolically represent pieces of information that pilots organised into structures to make sense of vast amount of information available in flight. Pilots referred to these pieces of information as *references* that were in their *mind*. Hence this concept has been termed *Mind References. Mind References* were not explicit on displays or in the environment, but were meaningful pieces of information obtained by the pilot and manipulated in his/her mind. All *Mind References* were identified in the empirical study and through observation of training.

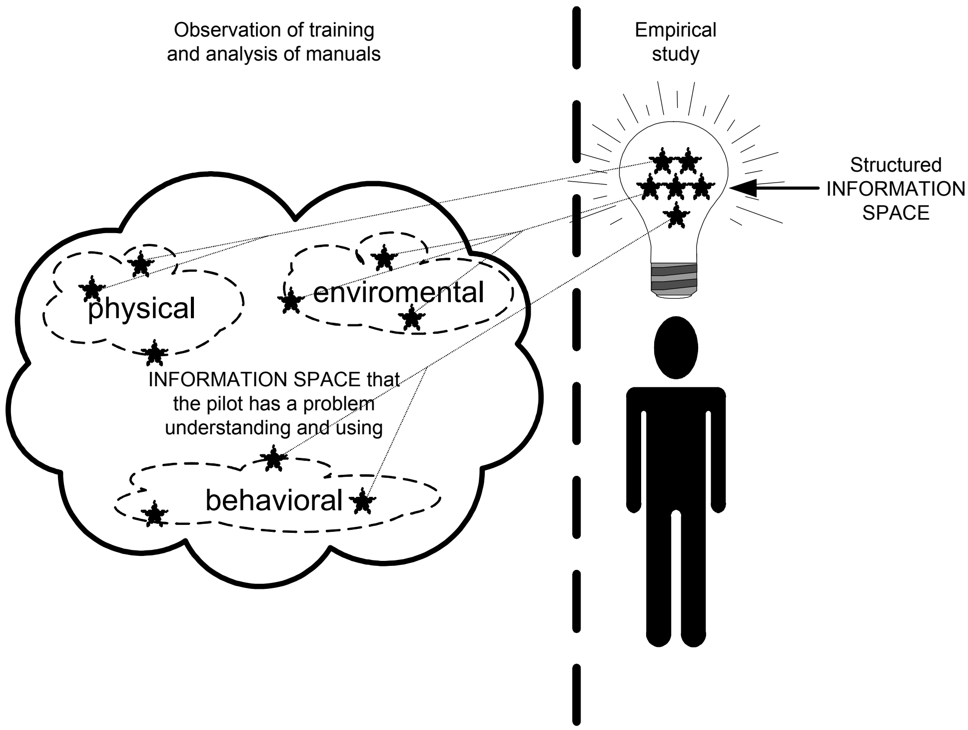


Figure 6.1: Information Space

Mind References are pieces of information that are relatively, or completely, unchanging and are chosen by pilots because they are considered reliable. A good example of human *Mind References* was suggested by Gibson, "the terrestrial horizon never moves. All optical motions *have a reference* that of a horizon. It is an invariant of ecological optics" (Gibson, 1979). *Mind References* use prior knowledge that can be a general to human or acquired by an expert in his/her domain, in order to make sense of information space and navigate in it.

Pilots identified these Mind References as specific and meaningful pieces of information in the environment and on cockpit displays and panels, which referred to, the physical state of the aircraft, the aircraft's behaviour and the environment. For example, a physical reference for the aircraft state might be the position of the flaps. The behavioural references determine current aircraft behaviour, or rather, the combined effects of the physical aircraft's state and external environment on the resulting behaviour of the aircraft. The environmental references are specific points in space, or on the ground, which establish the aircraft's path or the aircraft's position relative to them. All references were time-related or could be represented against a timeline.

From the empirical study (see chapter 5) it was concluded that none of the *Mind References* existed independently. Each reference was related to another reference or was *relative to something already existing in the information space*. References related to each other representing constraints, limitations and possibilities, such as a required or aimed position for the pilots to avoid or achieve. For example, the command pilots may use in operation, 'flaps to 50%', where '50%' represents a value out of total available 100 percent extension of the flaps. This example reference shows the aircraft structural limitations (i.e., physical), this limit being 100 percent of possible extension, and values between representing a measure of relatively how far the flaps need to be extended, i.e., half way equals 50 percent. The pilot in this case uses a meaningful reference to identify where ('flaps 50') is, and that the current flaps position is within the constraints (out of the 100 percent available). For behavioural references there would be speed and bank limitations marked at the outermost sides of the instrument.

An example of an environmental reference may be a specific section of airspace that needs to be avoided (or stayed within), which can be marked by several navigation points and/or and height restrictions.

Two or more references, from either of three categories of information, can be set as constraints. For example, flaps or gear extension (i.e. physical references), can limit the speed, which is a behavioural reference. In this case, setting of the flaps and gears would limit the speed to avoid structural damage, which is a constraint that pilots have to be aware of and maintain.

All *Mind References* that pilots select and set have *information structures* either determined or influenced by instruments, equipment and procedures. As is symbolically represented in the figure 6.1, above, pilots use *Mind References* to establish and structure the required information for efficient operation of the aircraft.

The pilot goes through a cognitive process when processing information during aircraft operation. The information processing observed during the studies is closely related to the Recognition-Primed Decision Model (Klein, 1989). Klein's model (Figure 6.2) represents a process of the operator recognising the situation through 'cues' (which may be considered similar to *Mind References*) that lead the operator to recognise 'patterns' (i.e., *information structures*) against a particular context (i.e., *contextual* level of understanding). These cues and patterns activate a 'mental simulation' (i.e., in the *time* dimension) using prior experience and understanding of how the systems works, then the operator arrives at decision of how to proceed. The cues and patterns in the Recognition-Primed Decision Model are similar to the *Mind References* that pilots use to make sense and navigate through the multitude of data available in a glass cockpit.

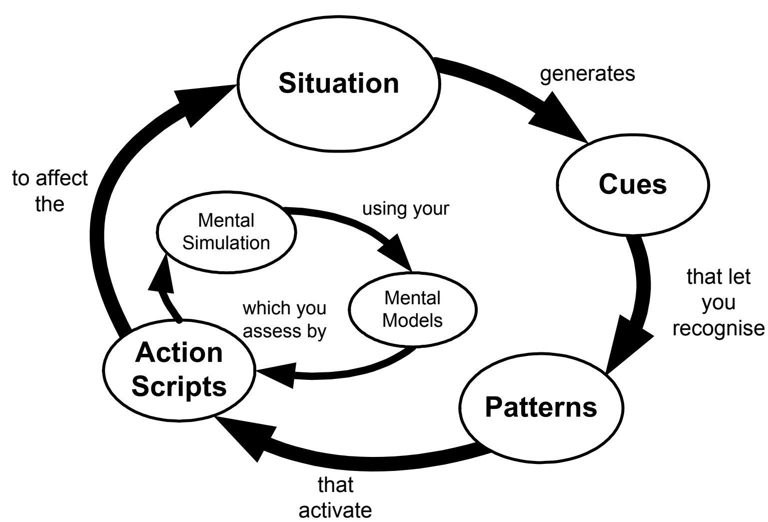


Figure 6.2: Recognition-Primed Decision Model from Klein 2004, p. 26

It was established during observation of training that pilots had problems with *three types of information.* Subsequently, during the empirical study it was determined that the pilots use these same types of information for the operation of the flight. To understand the information, pilots identified *Mind References* that helped them to perform their work more efficiently. Most of the *Mind References* the pilots established themselves, either from the display, the environment, or from their previous knowledge.

The problems that pilots' experienced in flight were mostly related to poor presentation of related of pieces of information (i.e., *Mind References*). In the problem definition (chapter 5), it was also established that pilots had difficulties on three ***levels** of understanding*: perceptual, contextual and semantic. The perceptual level concerns how information is presented; the contextual level concerns how information may be misinterpreted given its context; and the semantic level concerns how information can be misinterpreted ambiguously, or associated with unrelated information to provide incorrect information. The contextual level is broad in its definition, and includes the aircraft's physical configuration as this effects the activation of specific behaviours (for example, a button that would activate or not activate a function given present behaviour). Additionally, the absence of contextual information can give the incorrect meaning to the information presented.

The above three *information **levels,*** on which pilots have difficulty understanding, were present in all *information **categories***: physical, behavioural and environmental. This gave rise to a three-by-three table classifying all three information categories with the three levels of understanding that were observed during pilot training and the empirical study (Table 6.1). The columns represent *Mind References* (i.e., *WHAT …*) pilots used to make sense of the information space in the three categories: (1) the physical references that represent the constraints of the aircraft; (2) the behavioural references that represent set targets, limitations and the performance envelop for the aircraft; and (3) the environmental references that represent significant points in space, or on the ground, related to weather or navigational information. The columns of the table 6.1 represent (*HOW…*) the pilot interprets information, perceptually, contextually and semantically.

Representing Information	**Categories WHAT… →**	**PHYSICAL**	**BEHAVIOURAL**	**ENVIRONMENTAL**
Levels **HOW…** **↓**	**Description**	*Reference representing a physical constraint*	*Reference either representing current or future behaviour or the limitations of the behaviour/ performance*	*Reference established in the environment, either has to be maintained or signify the next event*
PERCEPTUAL	*What the pilot sees*	Flaps 50% position	Speed below 183	Crossing 10 miles mark and at 3000 feet intercept the finals course and start on the glide slope
CONTEXTUAL	*Why is it different given the conditions*	Final approach configuration vs. take-off configuration	Restrictions on behaviour due to noise pollution in the neighbouring airport area	Weather conditions, obstacles, or physical configuration

SEMANTIC	*What it means to the pilot*	The representation should not be open to misinterpretation

Table 6.1: Information Representation categories and levels

As can be seen from the example in the table 6.1, the information that the pilot used in both automated and manual flights (dialog Pilot M 14:32-14:51 and the same information was used in the automated flight) was linked and interdependent across three categories of information (i.e., WHAT…). The example from the above referenced dialog is placed in the perceptual level row in the table 6.1. This shows how the information extends across all three information type categories that the pilots used during the same flight stage (i.e. the final approach stage). The final approach had to start at a specific point in the environment, the behaviour was restricted by the configuration and the context was determined by the previous flight, the descent stage. The same applies during take-off, where the aircraft flaps are extended (i.e., physical) and the speed (i.e., behavioural) is restricted. All three levels are interdependent and can be influenced just by one category, such as environmental constraints. For example, environmental constraints might extend to acceptable noise pollution levels, which is a common factor in metropolitan areas. In this case, the descent point might be closer or further away from the airport, speed and flap extension might be restricted as well.

Apart from information dependencies observed during the preliminary empirical studies the information is also structured based on operation procedures, called Standard Operating Procedures (SOPs). SOP's include procedures such as; Air Traffic Control calls, ATIS information delivery, flight briefs, navigation plates and checklists. Information structure is also influenced by instruments and equipment, such as the Flight Management Computer. All these structures follow the pattern of the flight. Based on their experience pilots adapt these information structures and constantly use them in flight to organise, and make sense of, the vast amount of information they need to cope with. In the data analysis it was found that pilots constantly connect information and draw parallels between dependent pieces of information. However, disconnected information effects how pilots interpret it. The links and dependencies shown in table 6.1, above, are important for the pilot, and must be accounted for in the information presented if is to be comprehended unambiguously.

6.3 Time as a dimension in the information representation matrix

The information representation table (6.1) above is missing one important dimension for pilots in the aerospace domain, *time*. Throughout the observations of pilots in training, operating on-line, in the empirical study, and through the researchers personal flight training, pilots always considered their actions related to time. The empirical study and the problem definition chapter show pilots constantly use the dimension of time to understand the effects of: the current aircraft physical configuration, the aircraft's behaviour, and the environment. An example of the aircraft's physical configuration over time affecting performance might be that of extended landing gear increasing drag and consequently slowing the aircraft. An example of aircraft behaviour over time might be too low a initial speed at a low altitude, during final approach, which can stall the aircraft without allowing recovery from the pilot by increasing speed and lift. An example of the environment over time affecting the aircraft might be strong winds causing the aircraft to drift off-course. In all the above examples the effects are exacerbated with the passage of time if the pilot doesn't take corrective actions. Basis flight skills teach the pilot to ”think ahead of the aircraft at every moment of the flight.” This enables pilots' to account for effects that are happening over a period of time. Therefore, 'effect in time' has to be added as another dimension in the information presentation.

The 'effect in time' also happens in three instances: *prior to* any event, *during* the event (i.e., *current*), and *as a result* of the event (i.e., *consequence* and *intended*). To accommodate the 'effect in time' the above table (6.1) has been supplemented with this extra dimension to create the Matrix of Information Presentation figure 6.3, below. It shows the combination of all the dimensions of information presentation. Each dimension represents an area of information that pilots had difficulty understanding. The dimensions WHAT and WHEN deal with information that the pilot needed, and searched for, either on the display or in the environment. The dimension HOW deals with the way information was misunderstood by the pilot.

The information representation now has three dimensions: WHAT information a pilot uses, HOW this information is represented and consequently understood, and the dimension WHEN represents the 'effect in time'. In this way the Matrix possesses a time effect dimension necessary for the time-critical cockpit environment. Using this method of presentation shows that time as a dimension can influence every level and category of information. Throughout many flights pilots were observed to repetitively consider the effects of their current automation 'set up' on the future behaviour of the aircraft. Therefore, presentations providing reference with respect to past, present and future are considered particularly important for the *behaviour* information category.

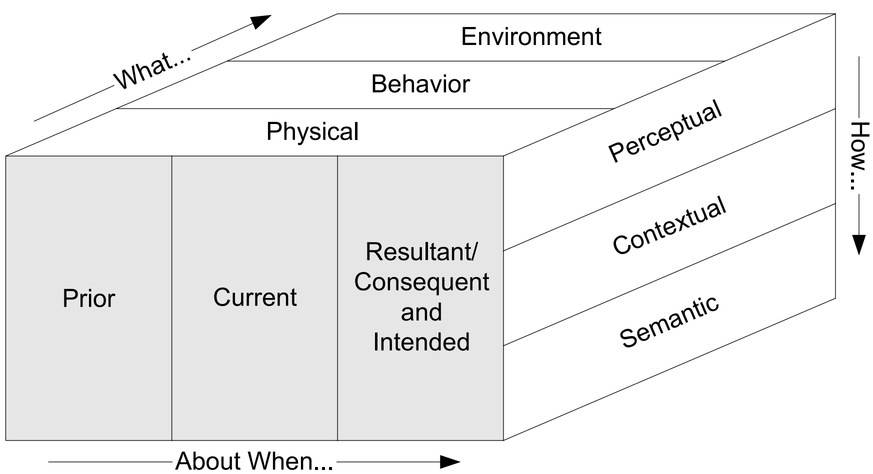


Figure 6.3:Matrix of Information Presentation

Time property is poorly represented, or not represented, on current cockpit displays, but dependence on time is an important aspect in the pilot's dynamic operating environment. Appropriate ways to represent time in system design is an ever-present problem and yet the predominance of Human Computer Interaction literature centres on displays that represent current events (Howard, 1999). Whilst existing literature reflects that the property of time may not be vital for systems that are not dynamic, in aerospace, however, *time* is a vital part of aircraft operation, and effects that happen with respect to time are complex and diverse. A variety of means of representing time are discussed below.

The figure 6.3 shows the aspects of time that need to be addressed and is based on the results of the studies discussed in chapters 3, 4 and 5. These aspects include; *what* time properties need representing, *what* and *when does* information need to be presented, and then in relation to *what*. The dimension of *time* will be examined in this section and also in the following discussion in chapter 7 (i.e., *how* to represent the time properties of information).

Presenting information that represents effects taking place over a period of time provides vital information for any operator controlling, using, or monitoring a dynamic system or operating in a changing environment. This has been stressed by several researchers before. To name a few recent proponent researchers, Wiener and Curry talked about the operators' need for trend information about potential failures in one of the first comprehensive reviews of cockpit automation problems performed by NASA (Wiener, 1980). Woods (1994) stressed the need to visualise the dynamic behaviour of the system, and Billings (1997) pointed out that automation needs to be predictable, and the pilot not only needs to know about its behaviour in the present, but also its effect throughout the flight.

There are two aspects of the *effect-in-time* (i.e., figure 6.4 in the WHEN dimension) that need to be emphasised and reviewed. One aspect of the effect-in-time is the dynamic property of the environment and it is an important property for pilots' to be able to track, as this was observed and discussed in the empirical study (chapter 5), and problem chapter (4). The second aspect, in existing literature Woods (1994) discusses this issue related to real-time visualisation of dynamic behaviour and in Howard (1999 p 65) it is stated that 'little work done on real-time visualisation of dynamic behaviour'.

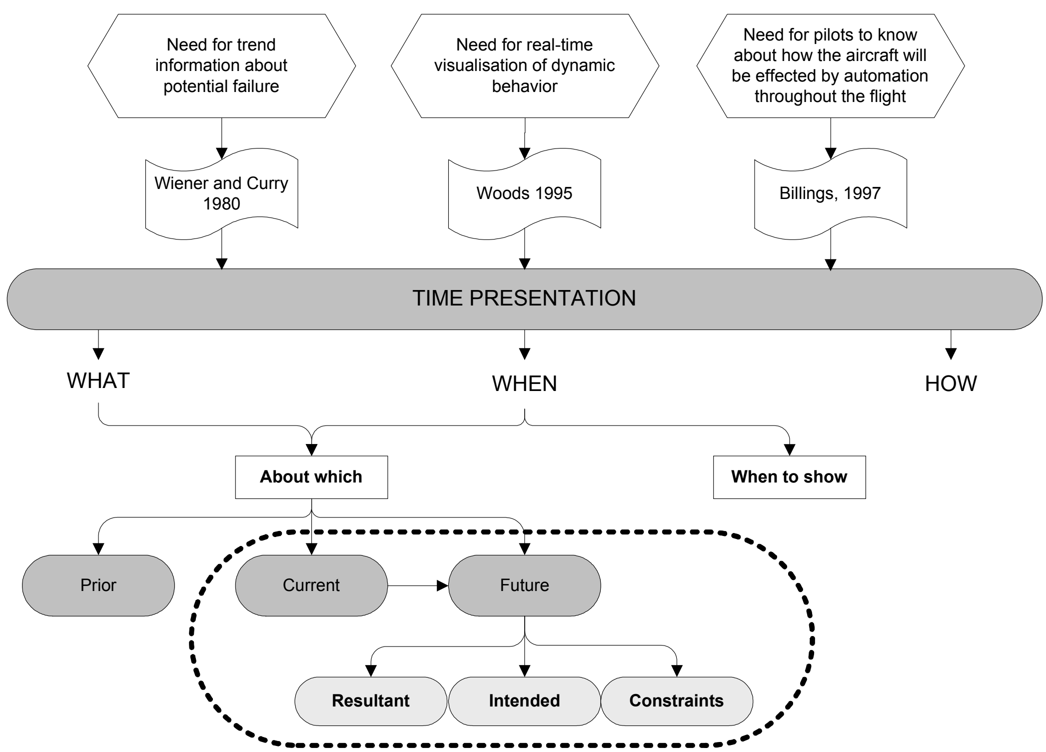


Figure 6.4:Required time-dependent information presentation

When considering the representation of any information the following questions need to answered; what needs to be represented, when, and for how long, and how should this be represented (Figure 6.4 above). Chapter seven will consider issues of *how* to represent time related information, and this section will consider the combination of the two questions, *what* and *when*.

From previously discussed studies it was elucidated that pilots want, at all times, to know and understand effects relating to aircraft state and behaviour, especially if the aircraft is being controlled through automation. This answers the question, *what* to represent (i.e., the aircraft state, behaviour and the effects on both). The question *when* looks not only at *when to show* the information to the pilot, also *about which* of the states, behaviours and the effects over time. There are three aspects of time that matter in a dynamic and rapidly changing environment; these are the *prior*, *current* and *future* aspects of the system and the environment.

From the empirical study it was obvious that pilots mostly consider the effect on the aircraft in the near future and on the next major event, such as an aircraft turn or a change of altitude. Fixed-wing aircraft have to maintain lift at all times during flight, which means constantly moving forward, this greatly affects information needs. Consequently, information regarding past events play a minor part in aiding the pilot in flight deal with future events. Two notable exceptions are; in monitoring the trend of fuel consumption this maybe beneficial to future events, and when navigation the reference can be behind this will help to maintain a specific heading and time from that navigational reference this can help the pilot to reorient himself/herself. However, even in these examples the focus of attention of the pilot is with what is ahead. Examining past information, as above, provides input to the pilot's concerns about the current aircraft state, behaviour and the effect in the future, i.e., what to do about it given current resources and how these may affect future flight stages.

The focus of this section is the current and future presentation of information, the figure 6.4, above, goes into more detail about what future information the pilot wants to know. From the studies reported in the previous chapters, it was found that pilots' often enquired about three different types of information about the future (whether flying with help of automation or without); these information types are the resultant, the intended and the constraints. All three types of information require some information extracted from current events to calculate the future information. Current information is also important as it provides a baseline, i.e., something to compare it to. Later in this chapter the comparativity-relativity of information will be seen to become a key principle. It is vital for the pilot to see the transition between current and future, for example, how presented information changes as aircraft transitions are made from one state to another. This information can be crucial to safety, for example, when making a turn en route from point A to B, the bank angle should not exceed safety performance limitations.

In slower dynamic systems, such as process control, presenting past information can be useful. For example, past trend and change information has been shown to be beneficial in situations where rate of change is low and so the visible effect on the interface is similarly low (McLeod, 1976; Wickens, 2000). Another example is that of historical strip-chart displays that show past and present information to help the operator mentally extrapolate future trends from past trends (Woods, 1981; Wickens, 2000). However, this approach is not appropriate for the aerospace domain as the cognitive effort required defeats the purpose of offloading mental work from the pilot to the automation. Indeed, in a discussion that follows it will be seen that the pilot rarely has all the information immediately available on which to mentally extrapolate, but the automation does.

6.3.1 Presentation of information about the future

In order to discuss the presentation of information about the future, first, current definitions of information about the future need to be established. Secondly, results and experience from previous studies about what information the pilots wants about the future need to be ascertained; and thirdly, these findings need to be presented in context to the body of existing relevant literature.

There is ample evidence that displays presenting some element of *the future* are beneficial to the operator (Wickens, 1989; Lintern, 1990; Trujillo, 1997). In fact, it has been previously stated, that in the aerospace domain it is vital and safety critical for the pilot to have a proactive position, where the pilot can plan and anticipate his/her own actions and the actions of the automation, rather then being in a reactive position (Amalberti, 1997). However, although this need is recognised, how to present information about the future, and what aspects of it will be helpful are questions researchers have been looking to answer for over half a century. The following paragraphs build on existing research, and the findings of this study, to suggest appropriate ways of representing information about the future.

Existing literature indicates that presenting time related information, especially about the future can be problematic. One issue related to this is *perceptual failure*, which occurs when operators' prior beliefs provide bias about what are the correct and salient information sources to sample to ascertain the current situation (Johnson, 2003). Perceptual failure is considered to have been a factor in a rail incident where train operators' perception of a previous sign influenced their late sampling of the next sign (Johnson, 2003). Therefore, it can be seen that as there is the potential for the operator to perceive the present situation incorrectly, through bias, providing future forecasts based on this may be similarly incorrect and misleading.

Similar problems exist in the cockpit, where the pilot thought they entered the correct information, but in fact the interface accepted erroneous information. In such a case by projecting this information into a future forecast aircraft set-up can show the pilot if, in fact, what he intends to happen is the correct action or not. However, although this might help to prevent the entry error from happening and becoming part of the aircraft set-up, it can also provide a false sense of security and let the operator sample the information less often, where the correct action would be to keep checking the current developing situation.

There is an existing body of literature on the presentation of information about the future; however, the terms describing this type of information vary from one researcher to another. To unify and present this existing knowledge in context an 'uncertainty scale' (Figure 6.5) is suggested. This measures the presentation of various information and definitions about the future, and so endeavours to aid the following discussion. The scale has five definitions of information about the future ranging from, *the extrapolated*, as information most certain about the future, to the most uncertain, *the probable*, as a definition where too many possible factors (i.e., probabilities) that can influence the outcome of the future event. Relevant to all five definitions is the fact that the further into the future the information is specified the more uncertain it becomes.

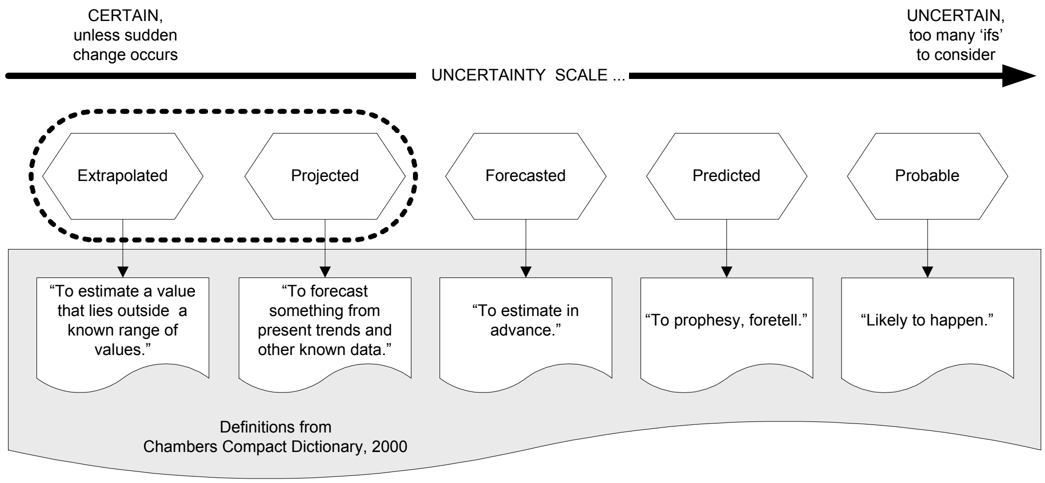


Figure 6.5: Uncertainly scale for definitions about the future

It is necessary to provide a level of certainty to the information presented about the future to the pilot. Hence, from the above (Figure 6.5) the appropriate future information to present needs to be within the areas of *extrapolated* and *projected* information. There are two considerations behind this; (1) automation should provide the pilot with information that is otherwise time consuming to calculate; and (2), in order to have a level of useful and constructive certainty the information should be based on current trends and any known changes that are programmed into the system. Any further projection beyond this is indefinite speculation, which the pilot can image himself/herself without too much mental workload. Hence, in this section the focus is on *extrapolated* and *projected* (Figure 6.5) information about the future.

6.3.2 The Resultant, the Intended and the Constraints information

As previously stated there is ongoing research, which began over half a century ago, on various forms of predicting systems to assist operators to have better control of systems. Consequently, there is a vast body of literature about displays that present future information, however, few concepts have reached actual operation. The figure below (Figure 6.6) graphically illustrates how samples from existing research and this thesis research can fit on to two important parameters about the presentation of information about the future. The horizontal line represents the uncertainly scale discussed earlier, and the vertical line represents time from the current moment to the far future. This graph illustrates issues such as, the uncertainty of information, how far into the future the projection is useful, and also the useful length of a future projection (i.e., for a single parameter, to track its progress and development).

The uncertainty scale, below, shows the degree of *uncertainty in information about the future* that is addressed by existing concepts and concepts formed this research. The uncertainty of information increases the further it is projected into the future, as is true for any display communicating information about the future (Wickens, 2000). Problems can arise due to erroneous information entered in the present (Johnson, 2003) and due to the consequent unreliability of future-related information presented to the operator (Wickens, 1999).

Based on the studies conducted in this thesis, there are three types of future information the pilots were concerned about and constantly enquired about; the resultant, the intended, and the constraints (Figure 6.6).

The figure 6.6 illustrates relative placement of the three types of future information (i.e., the resultant, the intended and the constraints) among current research that examines pilots reported problems understanding their aircraft's automation future-behaviour and 'intentions'. The resultant, the intended, and the constraints information are located on the 'certain' side of the scale, which can be guaranteed because it is programmed (i.e., the automation knows). The *resultant future* information presents automation behaviour that can be calculated from its programmed parameters, i.e., even if the parameters of the automation behaviour were wrongly programmed the outcome is predictable. This predictability is another strong reason for this information to be shown to the pilot in relation to its current operating parameters. There are, of course, circumstances where uncertainty exists, for example, if the aircraft's safety envelope is breached. In such cases the automation will have to change behaviour, but then the pilot can, and should, be warned about it (i.e. Pilot says, "…if I stay programmed on this course we can encounter a terrain and I will take these evasive actions").

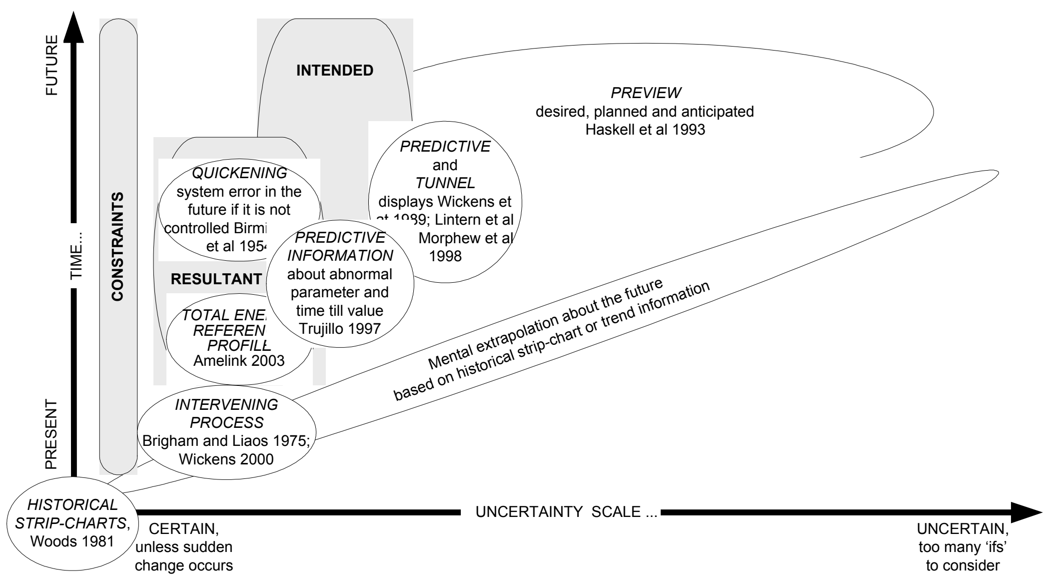


Figure 6.6: Margins of information about the future

The *resultant-future* is information about the outcome of current state, behaviour and environmental effects over a relatively short time-span in to the future (Figure 6.6). The resultant future representation is limited by either the next event or the next transition of aircraft state (*note*, the aircraft state includes a change of automation modes, it also depends on whether the aircraft is operated through use of automation or manually operated). Resultant-future information includes: the calculated path based on the current aircraft configuration, the automation state and aircraft behaviour. Additionally, resultant information has to be relative to the previously discussed categories of information, such as, the current aircraft state and behaviour and also the external environment. This also applies to all information categories. For example, if the aircraft were too close to the terrain the automation would present a warning and alter the aircraft's path.

Resultant-future type information, similar to that above, is discussed in existing research which is referenced in the two ovals at the top and bottom of the resultant outline in (Figure 6.6). The outline reference to the right also describes the representation of similar aspects of information to that of the resultant-future. Termed *predictive information,* Trujillo described and tested information represented in an alpha-numerical abbreviated format (Trujillo, 1996; Trujillo, 1997). This representation dealt with the warning indication of a *single* abnormal future-parameter and the time until that value was reached. Trujillo performed experiments with the warning indication occurring at 1, 5, and 15 minutes before the future event was to happen. These results showed that the warning alert did increase pilots' vigilance, through an increase in their scanning activities; however, this was at the expense of adding to their workload. Also, the length of advance notice provided by the alert warning was not found to greatly change pilot behaviour. However, resultant-future information, defined here, presents *all* (i.e., not only abnormal) known and relevant parameters about the current aircraft state and behaviour. All of these parameters are projected into the future, and the interaction and evolution of this information may provide a useful level of certainty to the pilot, rather than just an arbitrary timed alert (i.e., 1, 5, and 15 minutes). Birmingham referred to the resultant-future type of information as *quickened* information (Birmingham, 1954). Birmingham's research used the presentation of future tracking position based on current velocity, acceleration and position. However, this research did not display the current tracking error and so did not provide any information about the current time, on which to correct the current track (Wickens, 2000). In this way this aspect, i.e., presenting the onset of the error, is similar to Trujillo's work, but in this case in a graphical form. In comparison, the presentation of *resultant-future* information, from the empirical analysis in this study, suggests that presenting current information *relative to* future information in a continuous fashion may be beneficial even if there is no error in current parameters. As during the empirical study it was noted that pilots' were mentally calculating the future position of the aircraft throughout the flight from its current parameters, and monitoring the development of these parameters throughout the flight (see Appendix 3, Pilot debrief comment 10:33 and 10:42 manual flight). It was reasoned that in this way pilots' were assessing whether these parameters were developing correctly, or otherwise. By providing this type of resultant-future information on the interface the pilot can compare his/her view of how the flight should proceed with an outlook of the flight in the near future on the interface, thus relieving pilots from constant mental calculation.

This description of resultant-future information is closely related to the *Total Energy Reference Profile* described by Amelink (2003). The similarities between the *Total Energy Reference Profile* and *resultant-future information* are that in both cases the information produces a newly generated profile from existing data as a reference for the pilot. In the *Total Energy Reference Profile* information is given about the energy-state of the aircraft and this is represented in relation to the intended track. The differences are that the Total Energy Reference Profile represents only a few single parameters, i.e., the energy calculated out of speed and altitude deviation.

Some of this type information is already available in the cockpit from navigational displays, as in the trajectory projection, which displays the 'intended future'. The navigation display allows the pilot to project the route before it is executed, however, based on studies in this thesis it is considered essential to project the automation's future state and behaviour in relation to the aircraft's position on the map.

Presenting *intended-future* information aims to project the automation's intentions before they are executed, showing the pilot the outcome of newly programmed automation states and behaviour before they are activated. The *intended* representation of the future supports the pilots' need to understand the automation's intention, which was observed in pilot training and in the empirical study (see chapter 4) and is also a widely reported problem (Billings, 1997; Sarter, 1997; Sarter, 1995). Accident reports also provide evidence for pilots' need for this type of future information. For example, in the Bangalore Accident the pilots were confused about the behaviour of the automation and were preoccupied with trying to understand the nature of the problem, which diverted their attention whilst the aircraft flew into the ground short of runway (Ministry of Civil Aviation 1990; Aeronautica Civil of the Republic of Colombia, 1996). In accidents reported in Cali and Strasbourg the information pilots' entered into the automation altered the automation behaviour against the pilots' intentions (Aeronautica Civil of the Republic of Colombia, 1996; Pan American World Airways, 1990; Bureau Enquetes Accidents, 1992). In situations similar to these accidents, it is apparent that providing representations of the future intended actions of automation can help the pilot understand whether this is what they intend before they request the automation to execute the program.

The need for information of an intended future also coincides with assumptions in the Recognition-Primed Decision model by Klein (1989). When the operator goes through a decision making process, he/she considers one decision at a time starting with that which is closest to the situation. Relating this to the cockpit, if the consequence of the situation is mentally 'played out' by the pilot and does not provide a suitable outcome, the pilot projects the next possible action until a suitable outcome is 'visualised' in the pilot's mind, then this action is executed with the desired outcome. Therefore, providing a display representation of the *intended* projection of the future may provide the pilot a possibility to examine in detail the consequences of his/her actions before executing them.

Furthermore, existing research shows that information about the future, such as a *preview*, (e.g., display of the desired course in the form of a journey-path tunnel), is useful in systems that have a long system lags and time lags on feedback when responding to the operator's input (Wickens, 1986). This happens, for example, due to processing of the steering input effects and the water currents when steering a large ship in a channel. In order not to over-steer the ship a preview of the input effect is helpful to the operator. This specific type of information was not found to be essential to the pilot in our observations, mostly due the fast changes that occur in this kind of operating environment, as the controls provide very little lag in feedback to the pilot. However, the desired course displayed through a flight path-tunnel can be useful in military operations, when the pilot has to manoeuvre the aircraft at low altitude through mountainous terrain; but then, in this case, the display becomes a representation of the system and mountainous terrain constraints, rather then a feedback on the input.

The path-tunnel may also be useful during a landing approach to help the pilot see the margins of operation with reference to the glideslope that needs to be followed. In other relevant research on pursuit displays (i.e., path-tunnel), it was found that having one reference point to follow is more successful, rather then a compensatory display (Roscoe, 1968; Roscoe, 1981), which shows the difference in the input and desired, i.e., showing the error in the direction opposite to where the correction should be made. Here, evidence from the studies suggests this argument be extended to convey that the precision of pilot performance during landing would not necessary improve through the introduction of a four-sided reference tunnel-like display; as this provides the pilot a relative reference to the tunnel, but not an absolute altitude position reference to the runway.

The *constraint* future information that pilots appeared to search for in the studies described does encompass some features of the desired flight path-tunnel, however, the tunnel needs to be supplemented too to show the flight envelop protection parameters and the route restrictions, such as altitude and speed. Supplemented with this type of constraint information this type of display may help the pilot be aware of operating margins and how far he/she can take the aircraft and still remain within the flight safety envelope. To facilitate these extra features the relevant information about route restriction might be entered into the system; either through datalink by Air Traffic Control, or preprogrammed by the aircraft company, or programmed by the pilot; whilst the information about flight envelope protection (i.e., performance limitations) can be programmed by the manufacturer as a default settings.

6.4 Towards a theory of how *Mind References* fit into the design of interfaces and systems

There are various perspectives that can be used to explain how to transfer *Mind References* concepts to the interface. An Ecological approach (Gibson, 1979) has been chosen as fundamentally the Mind Reference concepts are in accord with assumptions behind Ecological Interface Design, that is well summarized by Lintern (2004): 'Ecological Interface Design results in a virtual world (i.e., a cockpit interface) that reciprocate the structure of the cognitive work'.

It was observed that pilots in several ways do attempt to restructure information in the environment to suit their existing knowledge. Pilots use existing information structures provided by the domain environment to help them to manoeuvre in the vast world of constantly evolving information. Pilots come up with strategies to overcome the shortcoming of information provided (for example, pilots use the length of a wing on the display as a measure of distance from the runway during circuits practice). The table (6.2) below shows the similarities identified between the Ecological perspective on interface design and how, from analysis, this study understood pilots' needs for a purpose designed aircraft information-space.

Interface Design		
	Ecological perspective (Lintern, 2004)	**Based on studies of pilot's information need** (see chapter 3, 4 and 5)

Why	Human action is constrained by the work domain	To operate pilots have to know about the surrounding environment and the limitations of the aircraft
What	Interfaces are mediated environments that can reveal the work constraints	Pilots search for information about aircraft limitations and the environment inside and outside the cockpit
How	Information can be depicted in a manner that supports direct perception of those constraints	Pilots develop strategies and use structures that separate masses of information into pieces by identifying and rearranging specific pieces of information to minimize cognitive workload and to operate the aircraft efficiently

Table 6.2: Similarities in Ecological Interface Design and the results of our studies

An Ecological Interface Design approach identifies and transfers the work domain constraints to the interface. (Lintern, 2004; Neekar, 2002). This approach is normally informed by the methods of Cognitive Work Analysis (Rasmussen, 1994; Vicente, 1999), however, here a purpose designed methodology has been used in the examination of the pilot's information processing. From the studies detailed in previous chapters it was found pilots' use specific pieces of information (referred to here as *Mind References*) to apparently observe constraints effortlessly. It was reasoned that to effectively/successfully make the transfer of constraints to HCI design guidance these specific pieces of information, or *Mind References* could be used. This new method is a departure from Cognitive Work Analysis, however, the new method is viewed as appropriate and complementary to existing methods in identifying how to structure, represent and transfer information on to the interface. A full Cognitive Work Analysis requires considerable time and resources, whilst the new methods present an economical means of levering into the problem of the transfer acquired knowledge from the analyses on to the interface.

There is a large body of specific literature and strict *standards* that govern the visual representation of information in the cockpit, for example industry design standards (e.g. UK Defence Standard for Large Aircraft 00-970). However, *concepts* are presented here that may help to provide guidance and choices, during the cockpit design stages, to determine what and how information should be, and can be, represented to enhance pilots' understanding of information. Providing concepts for guidance on the design of appropriate information structures and representations at this stage of development, rather than retrospectively, may also help pilots' to manage information better and so improve their overall flight efficiency. The next section in this chapter looks in detail how Mind References are use to guide cockpit design.

6.5 Mind Reference framework for information systematization and presentation

The concept consists of a matrix that comprises the definition of a set of Rules, Structures, Strategies, and Relationships (Figure 6.7). The concept helps to organise information throughout the information-system, as well as to help identify and explore possible presentation modes. The concept uses analysis from the previously discussed studies (explained in chapter 3, 4 and 5) using data, such as, the pilots' interpretations of their mental representation of information (from pilots' debrief comments), and through their experience knowledge (in part gained from the researcher observing and following parallel flight training). These inputs are recorded in the matrix and may be used on demand as a source for inspiration on guidance for appropriate information-organisation and presentation for cockpit design. It is stated that representations permit the complexities of the real-world to be simplified with limited risk (Amalberti, 1997), however, these representations must be appropriate. Domain Rules, Structures and Strategies may be extracted from matrix to guide such cognitively efficient representations.

It is intended that during the design/composition of a new information-space 'step-principles' are followed. The step-principles seek to streamline the process of design and help avoid missing stages. The steps also indicate the appropriate time to use the matrix and Rules, Structures and Strategies. Iterations through the step-principles may help to fine-tune the final information-space design, comprising the interface(s) composition, and the whole layout.

6.5.1 Mind References framework 'step-principles'

To use of the Mind Reference framework in design as it is intended the 'step-principles' need to be followed in the sequence shown below (Figure 6.7).

The first 'step-principle' is concerned with the format of information displayed to the pilot so that it is *consistent with the cognitive demand*, through use of the Skill Rule Knowledge principle (Rasmussen, 1994). This is important because it is known that the format of the presentation of information can change the nature of the problem, and further, it has also been suggested that an appropriate format of presentation can be used to solve information problems (Woods, 1995). However, this latter and more general claim has yet to be accepted and applied in the aerospace industry (Diego Castano, personal communications, Boeing, Seattle, 19 May 2005).

The first step towards finding an appropriate format is to match the task-type with the operators' abilities. In this way the form of the presentation should be determined by the evident nature of the cognitive demands in conjunction with the nature of the information to be represented. Following the Skill Rule Knowledge principle for information supporting skill-based behaviour (e.g., the perception-action elements of flight control), this should be represented in graphical forms that can be recognized intuitively through appropriate visual parallels, either innate (through common-life experience and language, e.g., land and sky separate with a *horizon*tal line) or through skill specific engrained coding (e.g., an 'X' symbol is used to close Microsoft files). If rule-based behaviour is to be presented it should follow a logical sequence, whilst knowledge-based behaviour should be presented using references to specific instances of this information.

Alphanumerical presentations, although often providing precise values when compared to pictorial and graphical presentations conveying similar information, leave the cognitively demanding task of determining the information's significance through calculation and comparison (through searching for other relevant alphanumerical display) by an operator. Additionally, alphanumerical displays may be chosen for their relative cost and compact spatial properties. Since the alphanumerical presentation often can be overlaid on pictorial information, it may be argued that, if required, a precise element can be supplemented to a pictorial/graphical display without much additional cost. However, it is argued here that comparison to, or presentation in terms of, other vital performance parameters of the aircraft presents more meaningful and efficient information then numeric information. In other words, through graphics, schematics and pictorial displays information from currently spatially diverse instruments may be integrated to convey simple significant information. This argument agrees with established literature in cognition indicating “Pictures tend to display information in a meaningful way that is compatible with mental models of the world condensing information into readily recognised gestalts in which relationship are clear” (Stokes and Wickens 1988).

Consequently, most of the presentation solutions suggested later are pictorial and graphical solutions overlaid with alphanumerical characters. Another reason for choosing a graphic display is that an aerospace display should be considerate to the fundamental instrument scanning techniques pilots’ are taught. The scanning technique originated in parallel with analogue instrument technology and the previous generation of analogue instruments technique permitted the pilot to ‘pictorially’ scan all the instrument indicators, knowing roughly where all the dial indicators should be positioned (e.g. all engine instrument point in the same appropriate for a phase of flight). From scanning these instruments if one instrument indicator was at an unexpected angle, it stood out, and showed quickly there was likely to be an anomaly (e.g. lower or higher indication on one engine than the other). It has already been found that some recently introduced digital displays are incompatible with this technique and so have had to be modified. Moreover, pictorial representations were observed to be used by the pilots’ themselves in training where the pilots’ used blackboard and chalk, and pen and paper to communicate and synchronize among themselves their views and concerns of their forthcoming flight.

The second step-principle is used to identify *Rules, Structures and Strategies*, that are relevant to the tasks performed by the pilot. For example, when designing for a task where the pilot will be monitoring information one of the relevant rules, established during the empirical study, is that ‘the pilot needs to stay ahead of the aircraft’. Therefore, if the pilot is monitoring recently briefed information, the information structure needs to reflect the briefed structure on the display, so that the pilot can compare the actual flight progress with the briefed flight stages. Also, should the pilot need to monitor the aircraft’s relative distance from navigational references, the strategies observed already in use by pilots in the empirical study again indicate appropriate presentation modes that may be used formally to assist in the presentation of this type of information in a new display. For example, pilots in flight were observed to use the size of the ‘wing’, presented on the Navigational Display (ND), to measure their relative distance away from the runway during a circuit turn. This indicates similar comparative, or relative, types of information presentation are appropriate to display information of this nature.

The third ‘step-principle’ is to o*rganiz*e the existing relevant *information rules, structures and strategies* that have emerged through proceeding through the first two step-principles. This step-principle involves examining the nature of the information to be presented against the existing Set of information Rules, Structures and Strategies and to note where information needs display commonalities and where the differences are distinct. In this way the existing rules, structures and strategies can be preserved in the new display. This stage is important not only when considering the display of exactly the same information in a new way, but also when considering presenting additional information in an appropriate manner.

Like the third step–principle the fourth step-principle relates to the organisation and assessment of information needs, however, in the forth step-principle the information is assessed in relation to the pilot. In this way the information needs are systematically worked through the *Information Matrix* to identify the most effective way to represent information in accordance with pilots' previous experience, knowledge, abilities and task requirements. Here the matrix acts as a framework for the designer to explore possible representations, rather than a formula to present the designer with a single definitive 'correct' representation. Rather, working through the matrix helps to define and then refine an information representation, by first permitting the generation of a possible representation and then using the matrix to narrow and focus this down into an appropriate format.

Appropriate information representations that fit with pilots' information perspectives can be arrived at from first identifying appropriate *Mind References* (see discussion earlier) from the matrix. The *Mind reference* concepts introduced in this thesis fit within other current research that highlight that problems exist in the aerospace domain due to communication not being made from the pilots' perspective. For example, Hutchins and Holder commented that pilots' training difficulties could be overcome if training materials were communicated to pilots' in pilots'-concepts. (Hutchins, and Holder, 2000). From the previously reported studies in the thesis it was ascertained that to understand how the automation controls the aircraft behaviour, pilots use their own information structures, comprising *Mind References*. Pilots' use *Mind References*, and structures constructed from Mind references, to orientate themselves in their information-space. To identify the appropriate Mind References for design guidance, the information matrix needs to be followed, as described below:

- Identify which out of three elements in the CONTENT dimension (i.e., *What*: Physical-Behaviour-Environment) are to be represented;
- Ascertain between which, or with which, of three elements in this dimension *relationships exist*, and determine the nature of these relationships, such as dependent, complementary, facilitating or obstructing;
- Move on to the dimension TIME (*When…*) to establish, whether or, which aspect of time needs to be represented, i.e., *prior*, *current* and/or *future*;
- Move on to the dimension UNDERSTANDING (*How…*) to determine the appropriate presentation. Reference the presentation against the perceptual, contextual and semantic levels to avoid misinterpretation. To do this the following questions are suggested as guidance:

Guidance Questions to Support Appropriate Information Presentation along the UNDERSTANDING Dimension of the Matrix

1a. Is there an existing *perceptual representation in the domain* or operator's experience?

1b. Is it an appropriate perceptual representation for this task, for this interface?

2. Is there a *human known perceptual presentation*, such as a metaphor?

Note. This question originates from findings in both the observational study, and the empirical data that indicate pilots commonly use metaphors (e.g., pilots communicate directions as hour numbering on the clock face – "traffic eleven o'clock"). These findings are in agreement with the statements written by Larkoff and Johnson such as "human thought processes are largely metaphorical", and further more "the human conceptual system is metaphorically structured and defined" (p. 6) (Lakoff, 2003). Consequently, it was considered as pilots' were observed to use information in the forms of metaphors, applying similar metaphors in the interface may help associate information faster and more intuitively.

3. Does the *context dictate how* the information should be represented?

Note. This question can also be phrased in another way; can this information be interpreted or misinterpreted in different way given the context? If the information can be misinterpreted, then the presentation has to be adjusted. Context is a widely discussed area in the field of Human Computer Interaction, and has been examined in Ubiquitous Computing which concerns the availability of information on demand in a specific context. However, here the issue of context is approached from another angle, where the context provides supplementary meaning, or aids interpretation. A body of literature (e.g. Woods, 1995; Wickens, 2000) stress the importance of putting data into context for ease of interpretation and better understanding. The findings of the observational and empirical studies also point to this, indicating the use of context to add to the meaning of information, where context can influence the interpretation of the available information (e.g. present information with use of context - if we present key numbers at key location, such as 180 at the bottom and 90 on the right of the circle on the display, given the context of a cockpit and Primary Flight Display it will be read by the pilot as compass indications).

References can also be identified by the context they are used in, even if only partial information is given about it. For example, in the empirical study, when ATIS information was read to the pilot, the Air Traffic Control mentioned only numbers, however, the numbers in that information structure can only represent the wind direction, i.e., '*140 degrees, 15 knots'* (see dialog ATC 09:51 M). In the above case, although the information was not complete, the context of where the reference was used and the structure of information gave definite clues to the pilots to what the Air Traffic Control was referring too (e.g. ATC 09:51 M: 'All station in bound Sydney, Sydney terminal information bravo is about to be recorded duty runway 16R, switch now, *140 degrees, 15 knots*, QNH 1022.'

This section also includes and uses the concept of a 'frame of reference' (Pinker, 1997; Wickens, 2000). In order to access information accurately, quickly and also avoid misinterpretation, *there is a need for a perspective on information*. The requirement for a relative perspective comes from our innate experience of our own body, this provides us a point of reference to determine, the up and down, behind and ahead. Similarly, Gibson (Gibson, 1979), although not discussing frame of reference directly, (i.e., the observer) examined optical flow, which must have a frame of reference, either suggested on the display (e.g., the view from the pilots seat given a set position in space) or the pilot himself/herself looking out of the cockpit window creates a frame of reference. More relevant to aerospace, this concept is later discussed as Global Optical Flow (Larish, 1990), where the frame of reference is determined by pilot's velocity and height. Moreover, the information to be presented in context, or using a context to add meaning, has to be presented *relative to an already existing object*, which again presents parallels to the situation described earlier where our body provides us with a relative association to the objects surrounding us. This, *relative to* quality allows three characteristics to the interface:

(i) All things presented will be relative in size to each other and allow pilots to use a strategy they were often observed to use (e.g. wing size relative to the distance to the runway).

(ii) The meaning is clearer if it is based on comparison, or contrast, against a known, or established fact/figure/parameter, such as Woods describes "meaning lies in contrast" (p. 174, Woods, 1995).

(iii) If all pieces of information show relationships between one another, all information will be connected on the interface and throughout the system, allowing pilots for a potentially easier and swifter quicker search.

When considering the *relative to* step it is also important to *highlight changes and transitioning events*. Providing emphasis to the operator at these points has been stressed by previous researchers (Woods, 1995). Additionally, during the observational study it was noted that pilots' used events, such as natural turning points in flights - cruise or top of descent, as cues to assimilate the information around them, whilst major expected changes, and events, were used as *Mind References* around which the information was grouped and linked.

Complementary to the above considerations, is the matter of providing the pilot enough time to be able to sufficiently sample the interface to detect the changing events. As was stated by Johnson, "forms of perceptual failure arise from the difficulty of correctly sampling many different items of information. This is not simply a problem in using foveal and peripheral vision to scan a large number of displays, it also relates to the rate at which information changes over time" (p 67, Johnson, 2003).

The context part of the matrix also deals with a vital part of current interfaces designed for time-critical environments. This is the problem of buttons, or keys, changing function dependent on their context, or configuration of the system (e.g., aircraft buttons may possess different functions dependent on whether the aircraft is in take-off or landing mode). In such cases, it is important that designs indicate change of context and change of mode, so that problems and anomalies do not arise. This situation is referred to by Woods who states "*Context, change and contrast*, (are) key features for discovering process anomalies, are rarely present. 'Disembodied', digital readouts show a current value for some aspect, without reference to 'normal' ranges, or the greater process they sample. " (Woods, 1994).

The last level of the Matrix, the semantic level helps the designer to ascertain whether the meaning behind the information presented is *open* to misinterpretation. The *semantic level* of the Information Matrix urges the designer to consider questions such as, what is the meaning of the emergent presentation?; and which out of emergent presentations are the most suitable? The latter question deals with the overall development of the presentation. It is important for the designer to make sure that the information associated with the presentation cannot change the meaning of already established presented information, unless it is intended (i.e., it might be necessary that newly introduced information reflects upon the meaning of surrounding information). Considering the risks of information misinterpretation, presented information should not be associated with non-related information.

The fifth step-principle considers the incorporation of additional relevant *emergent information* that has arisen from the use of *matrix*. This is where a variety of situations where information will be used need to be considered. It is anticipated that to complete this step will require additional runs through the matrix questions to blend-in and merge appropriate information together.

The sixth step-principle requires the *grouping of complementary* relevant information, to minimize the need for searching. There is a need to merge information because, as is stated by Wickens, "humans can process a small number of information-rich stimuli more efficiently than a large number of stimuli of small information content: decision complexity advantage" (p 532, Wickens, 2000). From the above, it may be to the advantage of the designer to consider computerised systems that provide the potential for a single indication for a set of connected input 'symptoms', rather numerous discrete annunciations for each symptom. At this step-principle relevant information will have emerged, however, the links the information might possess with context and situation (i.e., buttons and keys changing functions whether the aircraft in in take-off or landing phases) needs to be determined.

The seventh 'step-principle' recommends to *link information* on the interface and throughout the system to other relevant information *using defined relationships* that have emerged through the set of Rules, Structures and Strategies, and the established relationships determined from using the matrix.

The eighth step-principle requires the designer to *establish and to indicate meaningful connections*, associations and interdependencies between the information in order to show relationships between the displayed parameters and the whole system (i.e., speed is dependent to time and distance, so meaningful links between these parameters in a representation may be helpful). This is suggested as this may aid pilots existing problem-solving strategies enabling them to determine the exact information they need more easily.

The ninth 'step-principle' requires for all measurements to be *represented in comparison and relative to* either the absolute limits (e.g. performance parameters) or capacities.

The tenth step-principle recommends *representing* information *in meaningful units related to the parameter,* such as a timeline (in minutes or hours), height (feet or metres) or distance (miles or kilometres), to help the pilot to associate and assimilate the information.

The eleventh step-principle involves *minimizing routine computations* by associating related information and representing information in a form that pilots commonly reference it in. The assumption behind this step-principle is that ‘a pilot can only focus on a few parameters and the fact that automation was initially designed to offload repetitive calculations (Billings, 1997). Currently, computational demands on the pilot might be replaced by recognition demands (Hutchins, 1995) in this case the pilot needs to be supported by computational sub-systems. Not only pilots but all humans have a natural ability, and a lifetime of constant practice, comparing and estimating instead of absolutely measuring and performing time-consuming calculations. In the correct context estimations save time and cognitive effort, especially when other important tasks have to be attended to. Pilots’ have to perform constant vital calculations to monitor and extrapolate aircraft performance. By providing displays that permit the pilot to utilise this natural ability, by providing a means of comparison and estimation of vital parameters on the display, designers can assist pilots in their task by saving them time and cognitive effort. For example, currently pilots need to perform a two to three step calculation to determine level off altitude; (1) target altitude minus current altitude; (2) altitude to climb/descent divided by current vertical speed equals time to altitude. It is proposed this might be an appropriate feature that could presented in a manner to support pilots estimation abilities.

The twelfth step-principle advocates providing *a whole overview* for ease of information integration and association.

The thirteenth step-principle urges the designer to *provide detail in this overview* to enable the pilot to easily convergence, or zoom in, on information when needed.

The fourteenth step-principle suggests to the designer to provide relevant information on *future aircraft states*. Although this is the last step-principle, it is not the least important as it represents information that the pilots’ appeared to constantly search for (see Empirical study – chapter 5). Additionally, it was apparent that often in the absence of displayed information pilots’ would ‘construct’ information to provide reasoning for the automation behaviour. It was a constant message throughout the observation and empirical studies that pilots required information to aid them to comply with a fundamental rule of flying (i.e., ‘the pilot needs to stay ahead of the aircraft’). Pilots need ,and desire, to ‘see’ the future of the flight development, in one form or another, this is widely recognised and has been extensively discussed in previous research(Sarter, 1997; Amalberti, 1999; Billings, 1997; Endsley, 1995)

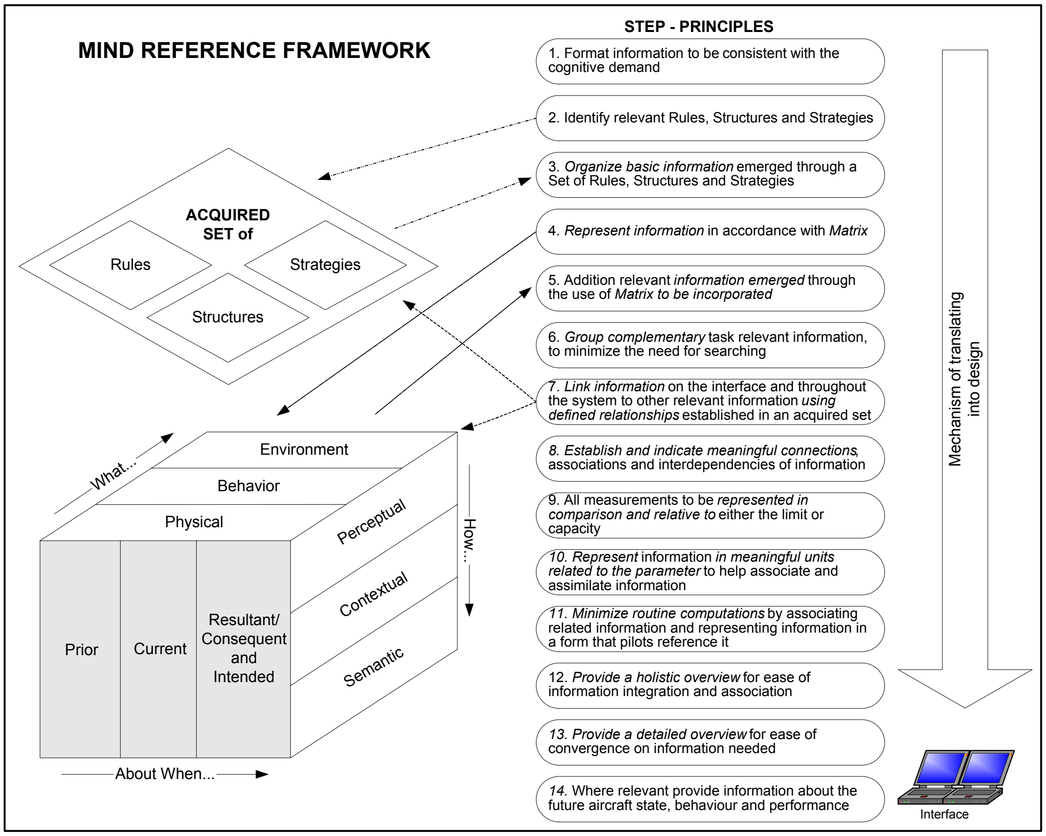


Figure 6.7: Mind Reference Framework

6.4.3 Fundamental rules for application of Mind Reference framework in design

It was established through the observation of pilot training, and also through the systematic analysis of aircraft operational manuals and design material, that the lack of consistency in the application of design principles was a key contributor to pilots' confusion. Lack of consistency, apart from being a widely reported problem in critical environments ('lack of consistency' p. 518-519 Wickens, and Hollands, 2000 and Woods, *et al* 1987), was also a major part of problems observed in training (see chapter 4) and the empirical study (see chapter 5). One of the two fundamental rules in the application of the Mind References framework is to apply it consistently throughout the system and interface design.

Rule One: Consistency in application of step-principles throughout the system design, in colour, symbology, location, meaning behind symbology. Consistency is vital to clear and unambiguous design.

Rule Two: All pieces of information, either on the interface or in the system, have to be connected to other related pieces of information on the interface, and represented in related terms (i.e., see relative to, contrast, change step), as well as connected throughout the systems via meaningful links. Conversely, information that is presented in isolation should be avoided, as this requires additional processing, and often requires searches for associated relevant information to determine its significance.

6.6 Conclusion

In this chapter the step-principles to be taken when formulating the presentation of information have been established. The next chapters provide the design of two types of displays on the basis of these steps, and Chapter 8 describes the experiment conducted to test the efficiency of one of these displays.

Chapter 7: Using Mind References Framework in design

7.1 Introduction

This chapter will illustrate how to apply the Mind Reference framework to two types of displays, one designed to help manage the automated systems of the aircraft, and the other designed to conduct basic flying tasks on a Primary Flight Display. Part of the second display will be evaluated and tested on pilots in chapter 8.

7.2 Appling Mind References framework in design – designing around a strategy

Throughout the empirical study and observation of pilots in training the pilots' asked constant questions about the automation; i.e., "What is it doing now, what is it going to do next, why is it doing that?" These questions were reasonable, because if the pilot were to fly the real aircraft him/herself, he/she would certainly be asking the same questions. Therefore, the question for designers in this instance is, can the pilot be shown what he/she wants to see?

According to several researchers currently pilots' have information presented to them in terms and concepts they cannot not manipulate (Hutchins, 2000). Rather, the information presented to pilots' is more suited to a communication to engineers. This point is succinctly made by Feary, "There are many possible reasons for the difficulties with pilot understanding of automated aircraft systems. It appears anecdotally, that one of these reasons may be a difference in perspective between the engineers who designed the system and the pilots who use it" (Feary, M., et al 1999). Based on the analysis conducted in this thesis attempts have been made to overcome these problems and present information to pilots, by using the Mind References framework developed (see Chapter 6 for detail). This framework is based on the analysis of pilots' basic training, operational flying, cognitive theories and theories of ecological design.

Existing research, and findings from this research suggest the most fundamental problem that pilots face is that current displays do not have much information, or the interface facilities, to support the pilot's need to plan ahead for each manoeuvre, or stay ahead of the automation and airplane in general. Through this omission one of the most fundamental rules of piloting, 'be ahead of the aircraft' is overlooked. The technology used in contemporary interface displays provides the possibility of helping this situation, however, currently the management of automated systems have now become an extra task for the pilot, even though the original intent of automation was to reduce some of the pilots' workload (Billings, 1997).

During flight pilots' must maintain *situational awareness*, part of which is defined as having an accurate view of the current and evolving situation. Despite the scientific vulnerability of this concept (Flach, 1994), it is considered an appropriate concept to use here to describe the capturing of significant elements of an important experiential phenomenon. To expand on this concept, in other areas of work, operators may speak of *being in the bubble* or of having a *mental model*. These terms capture the same sense of being able to visualize, conceptualize or anticipate and project the unfolding of events *prior to* actually experiencing them, and also of being aware of how events proximal in time and space can influence what is happening in the current time and position.

It has previously been established in this thesis that pilots use strategies, such as scanning, to help them deal with vast amount of information they need to operate an aircraft effectively. For example, to establish the aircraft position, pilots expect certain features to appear on displays or in the environment as time passes. In this way pilots' compare their mental flight plan with external references. Later in this chapter details are given on a proposed display that aims to present future-information to the pilot, such as intended and resultant, this will potentially permit the pilot to scan and compare their mental plan with the plan calculated by the automation.

7.2.1 Time Dependent Operations: The Mental Movie

Terms that are intended to stand for this form of *mind's eye* visualization have a long history of use, and abuse, within behavioural science, possibly because these terms have never received a formal definition. This is particularly true for the term *Mental Model*, which has a multitude of meanings in the scientific literature. Consequently, provided here is the reasoning for the use of the chosen terminology *Mental Movie*.

The term Mental Movie has been arrived at through combining the generic notions behind the term Mental Model, and the temporal aspects of Movie. It is argued that, in common usage, Mental Model refers to a form of mental visualization that allows one to trace through the sequence of steps or states of a process prior to the actual event. Therefore, upon this definition it can be seen that Mental Model captures much that is important in piloting. It permits visualization and mental projection of how one event leads to another, how events are interdependent and how they intertwine, and how informational resources must be accessed as events unfold. It does not, however, capture a critical element that became apparent through the analysis of the studies reported in this thesis, that being the time dependency of pilot expectations and actions. The studies revealed that pilots structure information, and their ensuing expectations, with time dependent relationships. Consequently, to include the temporal aspect in the terminology, the term Mental Movie is used.

It is reasoned that the pilot forms his/her *Mental Movie* of the flight during the planning stage of the flight. The Mental Movie is structured along a timeline, integrating key information profiles (distances from and to navigational points, turning points, flight level restrictions, speed restrictions, flight level changes with relevant speeds attached, points of contact with Air Traffic Control, time for checklists, etc.) against the timeline (Box 1). This *Mental Movie* then provides the basis for the pilot to confirm the progress of the flight as their expectations are compared with the actual unfolding events of the flight.

Box 1: A Plan Fragment as a Mental Movie

A pilot visualizes the following:

While in climb, fly 19 miles from navigational point A, then turn left to 230 degrees, level off at 5,000 feet, advise Air Traffic Control we have reached the requested position. Once established at the altitude, maintain speed of 210 knots

Therefore, a key use of this Mental Movie is in the confirmation of expectations. For example, one expectation within the scenario of Box 1 is a level off at 5,000 feet. Where this is under automatic control, failure to level off as expected will trigger action. Pilots also use these expectations as triggers, or cues, to prepare for significant events, such as landing or arrival at a waypoint. It is argued here that these expectations are an important structuring and monitoring strategy for the pilot and present a good basic strategy to support with automation.

Some forms of support are already in place and are successful on modern automated aircraft, such a PLAN mode of the Navigational Display, where all or most of the route is displayed on one display. This display enables the pilot to compare 'mental notes' on what the flight should look like from a view above, showing a lateral prospective of events.

However, a fundamental problem in the existing cockpit layout is that information is hidden and does not allow an effective comparison to be made, especially due to several influencing conditions, such as 'if conditions' that influence automation behaviour. These strategies are not working on existing displays. In light of the potential of current interface technology it is timely to take a new perspective on means of announcing aircraft state change to the pilot and presenting information in a manner considerate to pilot-like information strategies. For example, an interesting outcome from observational studies of pilots during flight operation is that pilots use a pictorial comparison strategy to see if the information they 'scan' (see chapter 4 for detail) matches up to their plan.

In the following paragraphs the Mind References design steps (see chapter 6 for detail) are used to conceive a display to help pilot operate the aircraft on the basis of the Mental Movie.

7.2.2 Applying Mind References step-principles:

The following paragraphs follow the development of the proposed display against the guidance put forward by the *Mind Reference* step-principles.

Step-principle 1: Format the information to be displayed in a manner *consistent with the cognitive demand*.

The Skill Rule Knowledge principle offered by Rasmussen can help the designer follow the guidance of the first step-principle (Rasmussen, 1994). This principle indicates that task types should be matched with natural human abilities, and that the form of representation should be determined by the nature of the cognitive competency that is deployed in conjunction with that information. Therefore, from the above principle, information in support of skill-based behaviour (e.g., perception-action elements of flight control) should be represented in graphical forms that can be recognized instantly. Supporting pilots' manual flight skill-based behaviour, was the focus of the proposed design, consequently, a graphical display was considered appropriate.

The proposed graphical interface can be seen in figure 7.1. It can be seen that this is a comprehensive *graphical representation* of the aircraft's flight-path. The aircraft's flight-path is depicted in four-dimensional space, with a pictorial timeline depicting the 4^{th} dimension of time. The pictorial display of the flight-path supports the skill-based behaviour required for manual operation of an aircraft, and so fits with the Skills, Rule Knowledge framework of Rasmussen et al (1994). The proposed display also provides the pilot a *holistic overview* of aircraft systems through the development of the flight, as shown along the *Timeline*. Additionally, the pilot can 'zoom in and out' (see later description) for a detailed view at any point on the timeline. It will be detailed later that both these facilities are important Mind Reference principles.

The *timeline* provides a way of *structuring information* about flight progress that is similar to the way pilots' structure information in their *Mental Movie* of the flight. The timeline serves as a common *Mind Reference* to aid pilots' recognition, association and assimilation of information. Key information is provided along the timeline to help the pilot see the functionality of the aircraft's systems at any moment of the flight, whether in the present, future or past. This graphic layout helps the pilot to manage the changing states of the aircraft's automation.

The proposed display includes a *'snapshot' capability* to support pilots' to be able to *convergence* on more detailed information they need. This proposed snapshot, feature would suspend the display in time to permit the pilot to examine it in detail, so that for a problem with any system, the pilot could use this capability to converge on the problem and formulate an appropriate corrective strategy. The step-principles 2 and 3 that are detailed below and explanations of how this guidance was used in the display are given.

Step-principle 2: Identify Relevant Rules, Structure and Strategies.

The *rule* that the proposed interface supports is 'to be ahead of the aircraft's current position, state and behaviour'. The *structure* that the interface supports is the pre-flight brief. The relevant *strategies* supported are, pilot's information scanning techniques (chapter 4), and how pilots' compare their *Mental Movie* of the briefed flight to actual flight events, which has already been discussed, above.

Step-principle 3: *Organize Basic Information* that has emerged through examining the relevant Sets of Rules, Structures and Strategies

At this stage it is necessary to add any further information needed to conduct the whole task (i.e., in this example the whole task might be defined as the entire flight, or progress along a significant flight stage) *onto a single interface along relevant parameter* commonly referred to by operators in the task (e.g. pilots often refer to a timeline whilst progressing through the flight). Therefore, in the proposed display the timeline is used to organize the basic information.

Step-principle 4: Represent information in accordance with the *Information Matrix.*

It may be recalled from chapter 6 that the *Information Matrix* is comprised of three dimensions; CONTENT (What…); TIME (When…); and UNDERSTANDING (How…), and each of these dimensions is further divided into three levels. These dimensions and levels will be considered in detail in the following paragraphs, starting with the first dimension of the *Information Matrix*, CONTENT (What…). This dimension comprises the information levels Physical, Behaviour, and Environment and the designer's first action it to consider the significance of these three levels on the information to be represented. Given that this interface is to help pilots stay 'ahead of the automation throughout the flight', all represented information will be about controlling automation or seeing its 'intentions' and actions. In this, probably exceptional case, information on all levels is effected, such as: on the Physical level (e.g. the aircraft's take-off configuration is different to that in level flight); the Behavioural level (e.g. as the aircraft transitions from take-off to level flight automation states and functions change); and the Environment level (e.g. terrain information, which may trigger activation of the automated flight-envelop protection routine).

Next the designer is required to ascertain between which, or with which, out of three levels of information do *relationships exist*, and what is the nature of this relationship, dependent, complementary, facilitating and obstructing. Although, there are many relationships relevant to the proposed display, appropriate examples include; Behaviour is dependent on Environment (e.g. where changes in terrain instigate the flight envelope protection routine); Physical is facilitating to Environment (e.g. changing the physical aircraft configuration through trim facilitates a straight course in a cross wind).

The next dimension of the Information Matrix to consider is TIME (When…). This dimension helps to establish, whether, and which aspect/s of time need to be represented. Since in the example display the pilot's need 'to stay ahead of the aircraft' is being supported, the information related to the future is important, however, as will be discussed in a later step-principle, all information is connected and should not be presented disjointedly unnecessarily. Consequently, the layout of the interface allows the pilot to view continuously the result of past actions, the effects of Physical-Behaviour-Environment influences on current, and the future developments of the flight according to that programmed form the pre-flight brief. Additionally, through highlighting key information along the timeline of the display, the pilot is made aware of changes in functionality of the aircraft's systems at any time of the flight, whether at present, future or past.

The next dimension of the Information Matrix is the UNDERSTANDING (How…) dimension. This is composed of the levels, Perceptual, Contextual and Semantic. The overall purpose of this dimension is to help the designer to determine the appropriate presentation and later avoid misinterpretation in context and meaning. In chapter 6 it was suggested that the designer use specific questions as guidance to help to identify appropriate presentation in this dimension. These questions are as follows:

- Is there an existing *perceptual representation in the domain* or operator's experience? Is it appropriate for this task, for this interface?

The observations and empirical studies suggested an appropriate representation within the domain. During the pre-flight briefings pilots' were observed drawing two or three-dimensional pictures of how they considered the flight would unfold. Consequently, this type of representation was considered appropriate to depict the flight. Additionally, depending on the operation pilots were communicating they used either distance or time or both as a parameter/s along which the rest of the information was placed.

- Is there a *human known perceptual presentation*, such as a metaphor?

The answer to this question again came from the empirical data. There is a ubiquity of maps and drawn directions in the aerospace domain, however, these are, of course, not exclusive to aerospace they are a widely understood perceptual presentation.

Whilst the preceding questions were to inform the designer on the perceptual level of understanding, the following questions are to inform the designer on the contextual level.

- Does the *context dictate how* the information should be represented?

This question may also be rephrased as follows:

- Can this information be interpreted, or misinterpreted, in different way given the context?

Considering the proposed display example the visible information presented along the timeline cannot be misread, since it applies to the whole flight, and there is no other context, other than the flight. However, what is needed on the proposed display is a need for a perspective on the information, i.e. a 'frame of reference'.

This contextual question was again answered from observing pilots' communicating with one another at the pre-flight briefs. Observing the drawings produced by the pilots' it was evident that the perspective on the information was chosen on the basis of the how pilots drew the flight, where the majority chose a left-most position to indicate the beginning of the flight, and depicted the progression of the flight rightward. It was considered at the time this maybe based on the fact that the aviation world predominantly communicates using the English language and English is written from left to right.

Additionally, the information to be presented in the context or using the context, needs to be presented *relative to already existing object, such as a scale.* For example, considering a human known example, outside the aerospace domain, this might be considered as our own body that gives us a relative association to our surrounding objects. With respect to the proposed display, the representation of the aircraft is presented relative to both the timeline and the route.

Also related to context is the need to highlight *changes and events.* This need was identified during the observations and empirical studies, as it was established that pilots highlighted major events and flight stages as points, where change or modifications occurred (e.g. Air Traffic Control contact resulted in change of altitude). Further, during flight major expected changes and events were used by the pilots' as Mind References around which the information was grouped and linked. On the example display changes an events are highlighted as marks on timeline, and anomalies and unforeseen events (i.e. those that differ from the flight brief), are highlighted on the timeline as soon the system has calculated them.

The last level of the Information Matrix is concerned with semantics and it raises the following questions: What is the meaning of emergent presentation? Which out of several emergent presentations is the most suitable? The meaning behind the information presented should *not be open to interpretation*.

Once the designer has progressed through the step-principles to this stage a prototype can be tested on pilots' for exploratory purposes. And may then consider the next step-principle below.

Step-principle 5: Consider the addition relevant *information that has emerged* through the use of *Matrix to needs to be incorporated*.

This is the stage where the variety of situations where information will be used need to be considered. Additional runs through the *Information Matrix* questions might also elucidate further information that is required to be blended-in/merged together with information already retrieved. For the example display reassessment of the CONTENT dimension (What…) and its three levels (physical, behaviour and environment) identified that it was important be able to show the effects of these levels on one another on the request of the pilot. As it was recalled that during the brief pilots often discussed the level and combination of automation modes they would use and the automation modes demonstrate information relationships between the levels physical, behaviour and environment. Therefore, the need to show the effect of automation mode at the request of the pilot, both in time and with respect to the environment was considered. Since, at this stage, the metaphor of a 'movie' on this interface had already been established, showing the automation set up of a system at a given point in time during flight as a 'snapshot of a moment' was considered appropriate. After some refinement of this idea, the facility for the pilot to preview the effect of automation setup against the flight profile would be helpful so the pilot could consider the effects of specific automation mode combinations (Figure 7.2).

Step-principle 6: *Group complementary* task relevant information, to minimize the need for searching.

On the example flight progress display, complementary information is structured along a timeline.

Step Principle 7: Link information on the interface and throughout the system to other relevant information using defined relationships that have emerged through a Set of Rules, Structures and Strategies, and established have relationships established from progressing through the *Information Matrix*.

In the example display relevant information is linked by, the overview perspective, and the reference to a common timeline and route. In this display additional relevant information can be sought by the pilot using the defined structure of the 'flight-plan';

whereby if data is entered about a specific point on the flight-plan, all relevant information surrounding that point may be retrieved.

Step-principle 8: Establish and indicate meaningful connections, associations and interdependencies of information to show relations of systems and parameters to assist in problem solving.

One of major problems reported during studies recorded earlier in this thesis (chapter 4) and also in aviation research over the last decade (Sarter, 1995; Billings, 1997; Lyall, 1998) is pilots' understanding of the effect of automation on aircraft performance, and the interaction of automation modes. Therefore, step-principle 8 points that providing indications of which part of the automation mode is effecting what part of aircraft performance would be helpful to pilots. In the example display interaction of automation modes with aircraft behaviour, performance and the environment is reported to the pilot at the snap-shot instances, as described above (step-principle 5).

Step-principle 9: All measurements to be *represented in comparison and relative to* either the limit (e.g. performance parameters) or capacity.

In the example display all the information is represented relative to the timeline, while altitude information is shown against the absolute lower-limit of the ground.

Step-principle 10: Represent information in meaningful units related to the parameter to help associate and assimilate information.

On the example interface display the primary parameter is time, where increments are shown along the timeline. To establish meaning to these increments, during a shorter flight these units may represent smaller units of time, whilst on a longer flight similarly greater spans of time. However, this aspect of the proposed display would have to be tested, as the rate at which information changes over time can influence the sampling rate of information by the pilot (Johnson, 2003).

Step-principle 11: *Minimize routine computations* by associating related information and representing information in a form that pilots reference it in.

For the example this display might include an automated estimated arrival time calculator can be given at major event points along the flight-path, as this is a routine calculation that currently the pilots' do.

Step-principle 12: Provide a *holistic overview* of for ease of information integration and association

The proposed display is an overall management interface and allows the pilot to see the effects of the automation setup and aircraft configuration, rather than individual pieces of information separately.

Step-principle 13: Provide *a detailed overview* for ease of convergence on information needed.

In the proposed display the detail view of automation mode interaction can show the effects of it on the flight-path in a unit of time (Figure 7.2 Snapshots). For example, during the degradation of the navigation system, the detail view can show how other systems compensate and where the information is taken from to support this compensation. In case of part of automated system degradation, the pilot can view how many autopilots are functioning and how the workload is distributed in the automated system and, by zooming out, can view the effect on the flight-path. The facility, on the proposed interface, for snap-shots can be supplemented by a feature enabling the pilot to 'zoom in and out' to gain a detailed view at any point on the flight-path. The zoom-in feature is important for pilots, for example, to enable them to converge on the information they need in the event of system degradation (e.g. engine failure, etc.) enabling them to be able to consider the whole system functionality given the malfunction. More generally, the zoom-in facility permits the pilot a detailed examination of a problem, with any system, and pilots may use this capability to help converge on the problem and formulate an appropriate corrective strategy. The zoom-out facility, in contrast, gives a possibility to view the larger effect of specific changes to parameters on flight performance and ultimately the whole flight-path.

Step-principle 14: Where relevant provide information on *future projected aircraft states*.

This is an important function of this interface. As mentioned above, the display is of the overall flight including a timeline and route information. Depending on the increments used for the timeline the flight may be projected into the future as far as the screen and time increments chosen permit. This feature uses the current system parameters and settings and using these as a projected dotted line (i.e. the projected course) ahead of the current position.

The figure 7.1 represents a model that encapsulates Mind References step- principles.

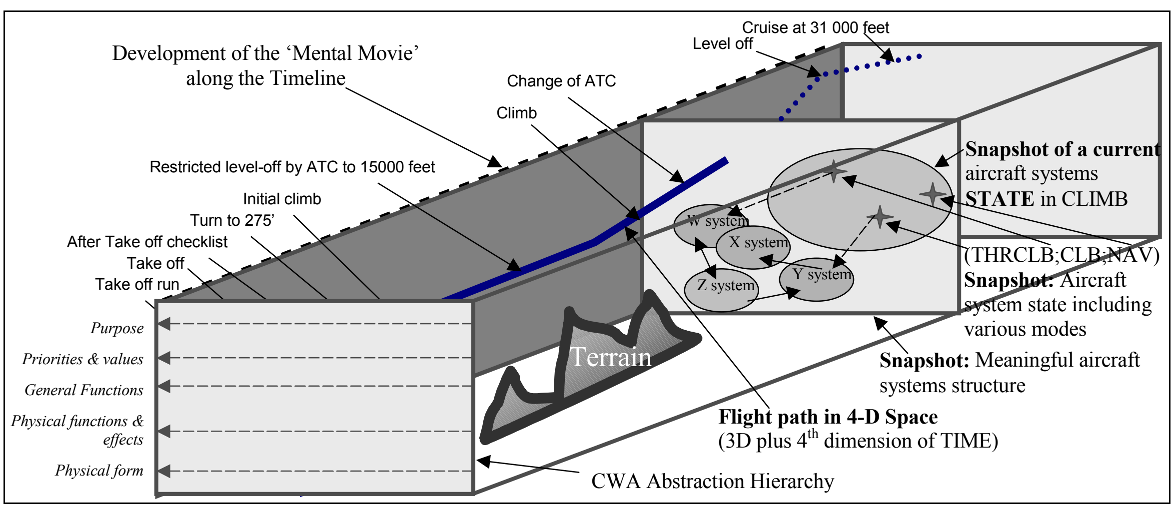


Figure 7.1: Prototype of a multi-dimensional, information-action workspace for an automated cockpit

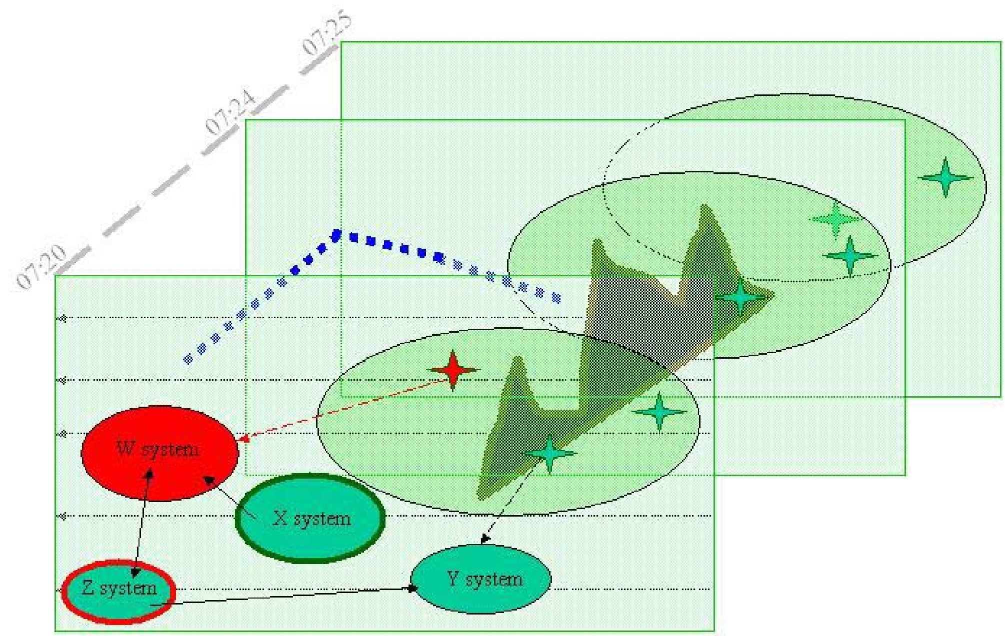


Figure 7.2: Snapshots of multi-dimensional, information-action workspace for an automated cockpit

7.2.3 Supporting a calculating technique through an interface feature

To cross check whether the automated system flies the aircraft precisely, or when the automation is not available the pilot goes through mental calculations to establish required references to monitor the progress. An example of this mental calculations that pilots performs to establish when to start levelling off, i.e. a mark at '*10% of your rate of climb*' to the level off altitude. This technique is taught to pilots at very early stages flying and is used throughout the flight.

Another mental reference that pilots need to calculate, but that is also unavailable on the display, is in the example below, it is a mark on 7 degrees prior to the required 'roll-out' heading. This indicates when the pilot will have to begin to come out of a 'bank' to roll-out on the required heading. The pilot calculates mental references using referenced information, such as '*height… rate of climb…turning rate'*. All the calculations below are measured in relation to a time, such as a rate of turn in seconds or a rate of climb in minutes.

Pilot 05:49 M: 'I will just explain something here. That might look like a fairly benign thing. All we are doing there just climbing and turning, but my workload is really increasing there, … *what rate I am climbing at, when I will need to start my level off and also when I will need to start my roll out from a turn. … how many degrees per second I am rolling at; how many feet per minute I am*

> *climbing at* … so what I'm looking for. I am having a look at my *rate of climb*. I am doing about 2500 feet/min, so 10% of your rate of climb is what you use to level off at for your *heigh*t so 250 feet before 3000 feet and that's when I've got to start my level off. And they are the things I am thinking about when I am doing that. Obviously approaching about 7 degrees at the *rate I was turning at* – rate 1 (i.e. 3 degrees per second or turn at the rate 1 is when the aircraft turns full 360 degrees in two minutes), because when you start your roll out.
>
> Ye, looks simple, but that what we do a lot of practice for instrument flying, doing coordination exercises, turning and climbing at the same time, descending…'.

The design process to support this calculating techniques using Mind References step-principles is described in the next chapter, where the design is also tested on and evaluated by pilots.

7.3 Next step

The following chapter (chapter 8) presents the results of the evaluation of displays features that are based on the Mind Reference principles, and have been implemented using the Mind Reference framework as described in this chapter.

Chapter 8: Designing and Evaluating Display Features based Mind References

8.1 Introduction

This chapter describes the design and evaluation of a display feature that was designed using the *Mind Reference* framework. The evaluation of this display feature was performed against the following hypothesis:

Using guidance from the Mind Reference framework in the design of displays results in display designs that can significantly aid pilots in their routine flight tasks, by reducing their time spent performing the task, and also by reducing their number of errors made while performing tasks.

In order to explore the information presentation issues discussed earlier in this work, and to gain a deeper understanding of the how *Mind Reference* framework presentation may improve these presentation issues, an evaluation experiment was conducted to test the above hypothesis. The experiment was designed to vary *Mind Reference* related presentation in four conditions (A, B, C and D) to identify the degree of their effect on pilots' performance. The *Mind Reference* developed display features were compared with the commonly used numerical representation of the same information used on most Primary Flight Displays.

The experiment comprised two parts. In the first part a between-subject design was used, where 40 pilots (four groups of 10 pilots) were assessed performing the task of calculating remaining time to target altitude, in total this comprised 320 trials (8 tasks for each pilot). Each group performed the experimental task on one of four display conditions: (1) A condition (control condition, using just numerical information), (2) B condition (*Mind Reference* presentation of a Level-Off-Altitude line), (3) C condition (*Mind Reference* of a Vertical-Speed-Triangle of 1-minute travel) and (4) D condition (complete *Mind Reference* presentation of all information needed to complete the task). In the second part of the experiment was a within-subject design on 17 pilots, where all pilots performed tasks only on two display conditions, A and D. This permitted the comparison on a larger number of pilots' performing the same task in two extreme cases, on the numerical and on the display fully designed using a *Mind Reference* framework.

The first part of the experiment permitted the examination of which features influenced pilots' performance and in the second part both display conditions were tested on the same pilots (within-subject design) to avoid individual differences influencing the results. The Figure (8.1) provides the analysis structure and highlights key results (i.e., including outliers) that guide the reader through the analysis.

Therefore, in testing the hypothesis firstly, combinations of the display features designed using guidance from the Mind Reference framework were tested to assess whether these helped pilots to complete an estimating task more effectively, in less time and more accurately in comparison to a display with numerical representation. The second part of the hypothesis test was to assess if more features implemented in the display from Mind Reference guidance, resulted in a similar increase in pilots' performance.

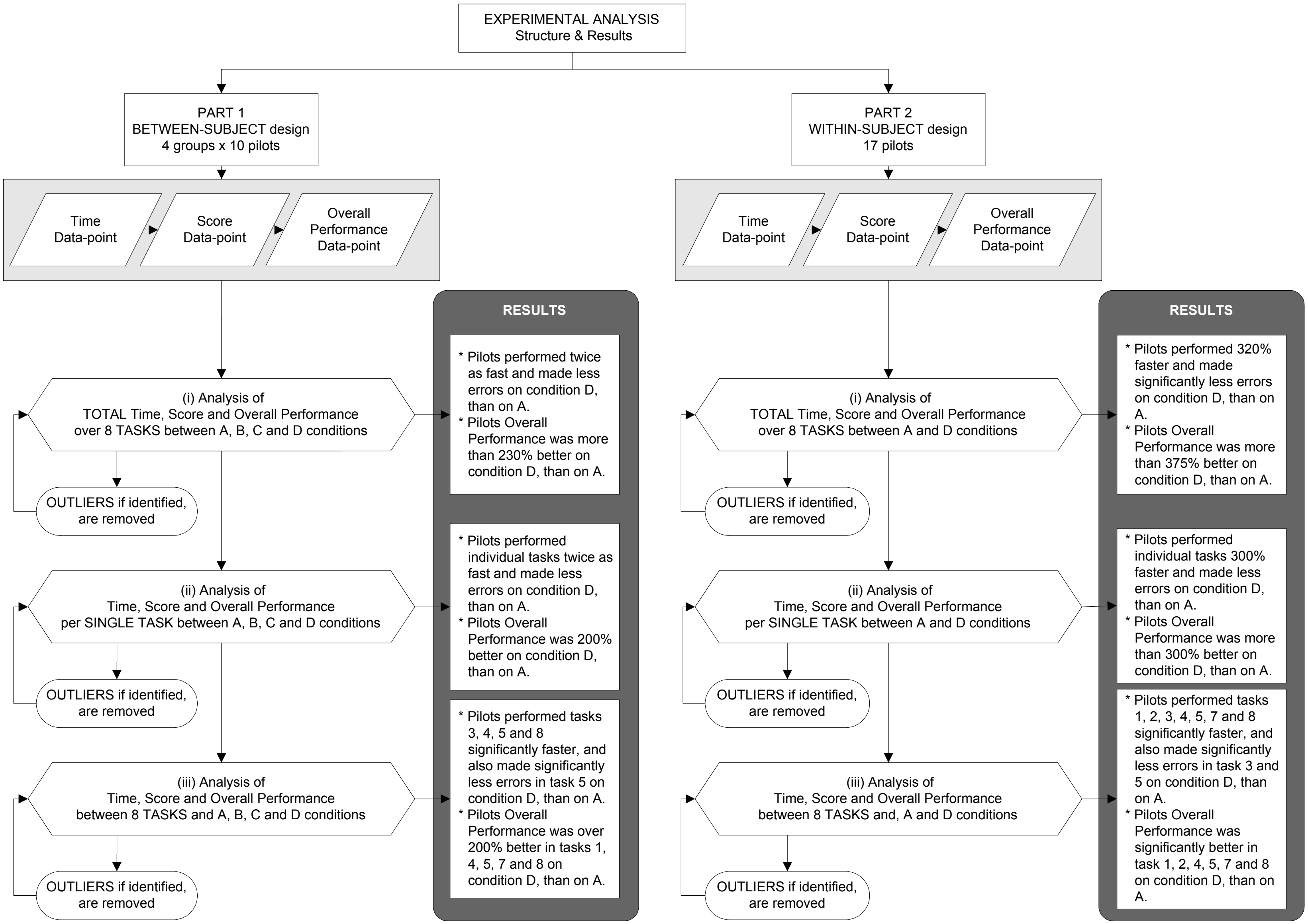


Figure 8.1: The analysis structure

8.2 Design Rational: Using Mind Reference Framework

Previous findings (discussed in chapter 3 and 5) showed that pilots, flying both automated and non-automated aircraft, constantly use a reference to time as a crucial parameter during flight. Moreover, this time parameter is a foundation upon which events become significant to the pilot, a concept termed in this thesis as *Mind References*. The concept of *Mind References* itself (discussed in chapter 6) uses broader concepts like metaphors (Lakoff, 2003; Pinker, 1997; Wickens, 2000) and visual cues in optical flow (Gibson, 1979) that suggest how humans naturally assimilate, acquire and use information.

Based on observations of pilots' in training, an empirical study and interviews with pilots it is suggested that pilots use such *References* to structure, organize and monitor the data presented to them from aircraft displays (Solodilova, 2003).

The *Mind Reference Framework* proposes several underlying interface design principles (Table 8.2) that, it is hypothesized, will combine to reduce workload upon pilots by reducing calculations and reducing mental processing. Further, it is proposed that these principles help assimilating vital time-dependent information to assist in time-critical situations.

***Mind Reference Framework* – Step-Principles**
1. The *format of information* displayed should be *consistent with the cognitive task*
2. *Reorganize* basic *information* needed to monitor the whole flight progress onto a single display *along a parameter* commonly referred to by operators (for example, a *timeline*)
3. *Represent information in units of parameters* and representations that are *meaningful to the pilot* to help associate and assimilate information
4. *Group complementary information*, to minimize the need for searching
5 *Establish meaningful connections*, associations and interdependencies of information to show relationships of systems and parameters to assist in problem solving
6. *Provide a holistic overview* for ease of information integration and association
7. *Provide a detailed overview* for ease of convergence on information needed
8. *Minimize the computation* of routine calculations by associating related information and *representing it in a form* that pilots *reference* it in
9. *Provide instantaneous relevant information about the future* aircraft states

Table 8.1: *Mind References* framework principles

Note:

The list of step-principles above is an abridged version of that presented in chapter six. The omissions are;

Identify relevant Rules, Structures and Strategies.

This was omitted for test as the relevant Rule chosen was, that the pilot should be able to stay mentally 'ahead of the aircraft' and this Rule was, in practice, embedded in the many of other features that were practical to test.

Additional relevant information emerged through use of the Information Matrix.

This was omitted as the purpose of the Information Matrix is largely to examine integrating many information sources, whilst it was only practical to experimentally test a stand-alone display feature.

Provide a holistic overview for ease of information integration and association.

Provide a detailed overview for ease of convergence on information needed.

These two step-principles, above, were omitted, again, as it was only practical to test a stand-alone display feature, whilst the two step-principles are concerned with information integration and management.

8.2.1 Display Design

Most of the Primary Flight Displays in glass cockpits provide the following information: aircraft attitude, air speed, altitude and vertical speed, heading and track, vertical and lateral deviation, autoflight and radio navigation information. However, for the purposes of this investigation a prototype display was designed using a minimum of information (air speed, altitude, vertical speed and heading), most of which is directly relevant to the task at hand. This information was translated into a variety of features, according to the step-principles proposed and then compared with the current, largely numerical, representation of the same information on Primary Flight Displays.

8.2.2 From concept to design

Table 8.2.2a shows how current numerical representations comply with the proposed step-principles and in comparison shows how the proposed features comply with these step-principles.

The step-principles should not be applied individually and are used in conjunction with each other. However, for clarity they are considered one by one to show how they form the display features (also Table 8.2.2a) and help to perform that task.

Mind References **Principles for task time to altitude**	**Numerical features on current displays** (Figure 8.2.2a)	**Proposed features in prototype display** (Figure 8.2.2d)
1. *Format information consistently with cognitive task*	Numerical tasks are cognitively demanding	Whole display designed for a routine calculating task, features designed according to further principles; shapes and distance in between are used to assist in faster

		calculation/estimation
2. *Reorganize information along a parameter*	Not supported	Information presented and referenced with altitude tape
3. *Represent information in meaningful parameters*	Mostly numerical representation	Time represented in height of triangle and dashes, vertical speed in units of time
4. *Group complementary information*	Not grouped	Group time, vertical speed and altitude
5. *Establish meaningful connection*	Not supported	Current altitude line is lined up with the vertical speed triangle; dashes lead to target level-off altitude, showing the path to be travelled; both altitude lines connect with speed and altitude
6. *Provide holistic overview*	Not applicable	Not applicable
7. *Provide detailed overview*	Not applicable	Not applicable
8. *Minimize computation* by *representing it in pilots' form of reference*	Not supported	Information combined (vertical speed and altitude to be travelled) and presented in units (minutes) that pilots require, i.e. height of the triangle equals one minute of vertical travel
9. *Provide instantaneous projection of future*	Not supported	Provides target level-off altitude in relation to vertical speed and dashes, helping pilots estimate time at a glance

Table 8.2.2a: Comparison of representation on displays

To investigate the hypothesised benefits of using the step-principles, and to assess the new features designed using this guidance, a routine piloting task was chosen for a new display design. This is a task where pilots' have to calculate the time to target level-off altitude based on the current vertical speed. The rational for choosing this task is discussed and summarized in the method section.

According to ***step-principle 1*** the proposed feature has to support pilots' cognitive tasks. For the purpose of the experiment a task that requires calculations was chosen – calculating the time to level-off altitude. When the task is established, the rest of the step-principles shape the display features to support the pilots' task.

Step-principle 2 – requires the designer to identify a general parameter that the pilots' will be referring to while performing the task. In this particular task it is the altitude parameter. The parameter should be represented as a continuum along which the rest of the information will be placed.

Step-principle 3 – involves identifying a parameter that pilots need as an outcome of their calculation. For this task the parameter is time, represented as increments, where one increment is equal to one minute. These increments should be represented in terms of the general parameter, the altitude. This will allow pilots to reference these increments (i.e. the time) against the general parameter (i.e. the altitude). Since the altitude is represented as height, we will use the height of an object as one unit along the increments (i.e. one minute). Also the height is a suitable representation of the unit, because the task requires thinking about vertical travel, up or down. This then helps the designer to think further about the type of object would be appropriate to use that can represent the unit of time. Since, in this example, a direction representation was being sought, the symbolic representation in a shape of equilateral triangle seemed appropriate.

Step-principle 4 – is responsible for grouping information required to complete the task. It has already been established that time and altitude should be grouped. Altitude described in units of time is also known in aviation as vertical speed. This leads to an additional meaning to the equilateral triangle, vertical speed per minute.

Step-principle 5 – establish meaningful connections. The designer may establish three of the required meaningful connections in this task. First, all current flight parameters have to line up together, i.e. current speed, altitude and vertical speed. Second, all future flight parameters also have to line up, i.e. future speed and altitude at level-off. Lastly, to aid the pilot in calculations connections between the current and future altitudes, i.e. the path to be travelled may be shown by consecutive one-minute dashes of the vertical travel. This representation connects present to the future flight parameters.

Step-principles 6 and 7 are not applicable for this calculating task. They are more suitable for other piloting tasks, such as monitoring and problem solving. However, these step-principles are described in detail and through application in chapter six.

Step-principle 8 – is achieved by grouping information appropriate for the task, which in this task is achieved through grouping time, altitude and vertical speed and representing these as an equilateral triangle.

This spatial representation in units of time (i.e. one triangle equals one minute of vertical travel) allows pilots to simply estimate the number of shapes that can fit between the altitude lines, instead of subtracting numerical information.

The equilateral triangle is one of many possible solutions that may exist and comply with step-principles (one, two, three, four, five, eight and nine), so the triangle is not necessarily the sole solution. Lastly (***step-principle 9***), an instantaneous projection has been already supported in the proposed design through the application of previous step-principles. Moreover, the height of the triangle and the consecutive projection of dashes provide pilots with the possibility of estimating time to altitude at a glance, rather than ‘crunching the numbers’.

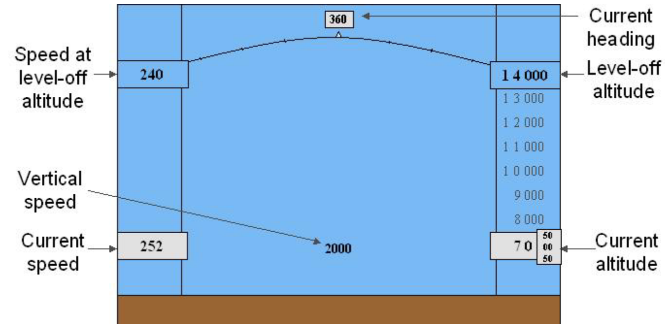


Figure 8.2.2a: Display Condition A

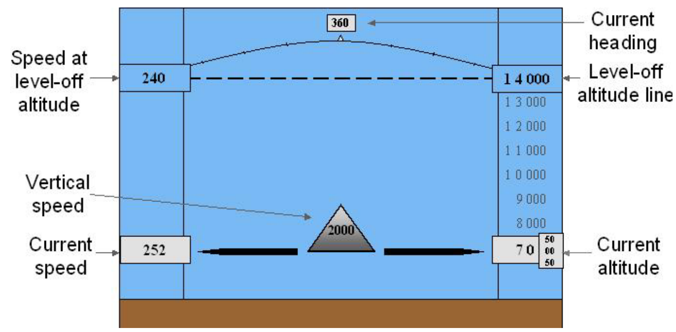


Figure 8.2.2b: Display Condition B

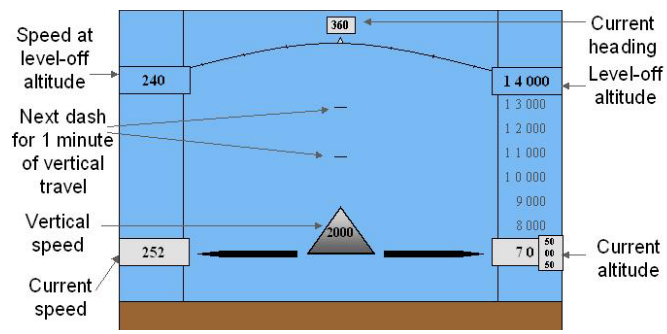


Figure 8.2.2c: Display Condition C

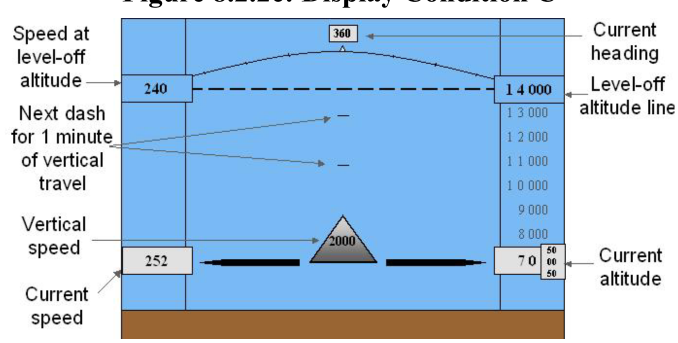


Figure 8.2.2d: Display Condition D

It may be apparent at this point that not all step-principles are equally applicable for all types of task. For example, some are more applicable to problem solving and monitoring tasks, which are equally important in any cockpit, but are not the subject of the current experiment.

From table 8.2.2a it can be seen that the numerical representation is not successful in the embodying these principles. The numeric presentations are limited and do not allow for visual comparison of relative distance and size. In this instance a numerical display makes the calculating task difficult, as not everyone is fluent performing arithmetic tasks. It was important to ascertain every participants (i.e. pilots in these experiments) arithmetic ability, in the experiments, to identify whether higher numerical ability would aid their performance on the numerical display.

8.3 Method – part (i), between-subject, 4 groups, N = 40

8.3.1 Experimental scenario

To test features developed using the *Mind References* framework on a prototype display one, of the many, repetitive calculating tasks was chosen, that of estimating the time to target level-off altitude. This is representative of other tasks, such as the calculation of the time to the next navigational point, and the distance over ground in a period of time.

The task of calculating the time to level-off altitude (Table 8.3.1a) is performed routinely throughout each flight and so should not be time consuming or cognitively taxing. It requires a quick and accurate answer, as well as quick convergence on the information required. Consequently, the quick and accurate aspects were of interest as measures of the participants' performance during the experiment.

Experimental task instruction
Calculate how much time is left to reach the level-off altitude from the current altitude take the following steps: • Level-off altitude minus current altitude equals remaining altitude → 14 000 – 7 000 = 7 000 (feet) • Remaining altitude divided by current vertical speed (feet per 1 min) equals time in minutes to level-off altitude → 7 000 / 2 000 = 3,5 (minutes)

Table 8.3.1a: Experimental task

8.3.2 Participants:

The sample of participants in the study comprised 40 pilots, i.e. ten pilots per condition. The participants were evenly distributed across all conditions. Two out of the 40 pilots were female. This means 5% of the all participants in this experiment were female, which is representative of the general population of pilots in aviation (Aviation for Women 2004). The average age of the participant pilots was 36 years old (SD = 11.8), ranging from 20 to 61 year old. The age factor was evenly distributed across all four experimental conditions (Figure 8.3.2a).

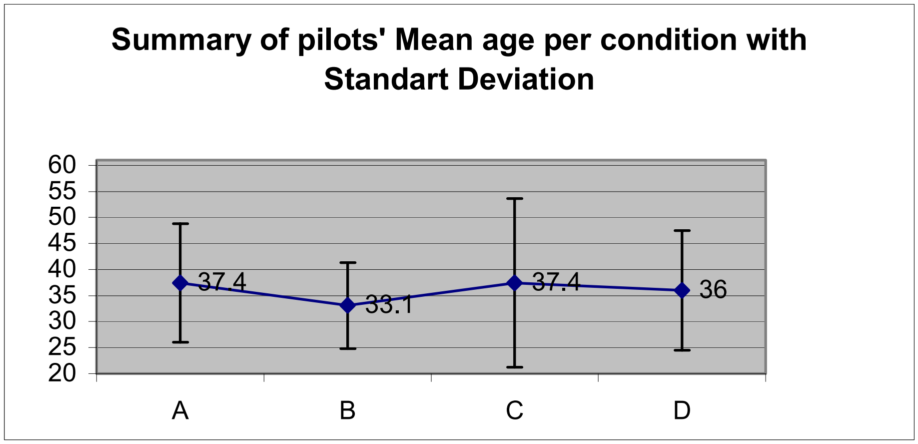


Figure 8.3.2a: Summary of participants Mean age

All participants were pilots, with total flying hours ranging from 80 to 10200 with an average of 3252 (SD = 2988). A summary of all pilots flying experience is shown figure 8.3.2b. It is evenly distributed across all conditions.

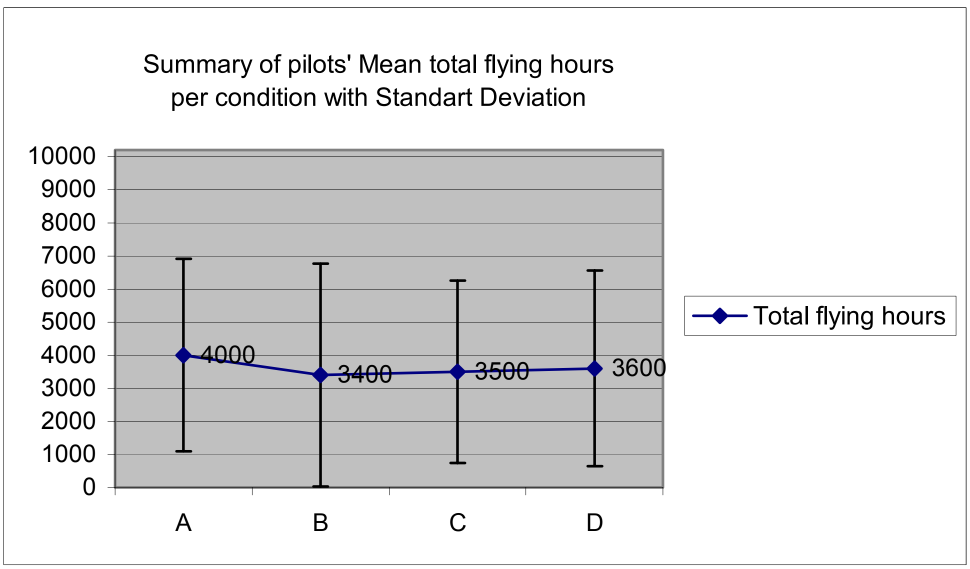


Figure 8.3.2b: Statistical summary of participants flying hours

8.3.3 Material:

Experimental prototype displays were designed using Microsoft Power Point. A set of pre-designed (i.e. by the researcher) slides was used, where each represented an individual task the participants' had to perform. The slide show formed a presentation consisting of eight different task scenarios. The participant controlled the speed of presentation of each slide, moving from one task to another at his/her own pace, using a keyboard.

The experimental displays were designed on the basis of a modern aircraft Primary Flight Display, showing all the basic information required to complete the experimental task.

There were four types of prototype displays to represent four experimental conditions. The experimental display condition A (Figure 8.2.2a) was a control condition that embodied none of the *Mind References* principles, and only contained basic numerical representation of information. The condition B display (Figure 8.2.2b) had the same information as the display A, plus an additional feature of a Level-Off-Altitude line. The display C (Figure 8.2.2c) had the same information as the display A, plus an additional feature of a Vertical-Speed-Triangle with reference dashes, where each consecutive dash indicated the next one-minute of vertical travel. The display D (Figure 8.2.2d) had all features together on one display, both in numerical and *Mind References* form.

The four conditions (A, B, C and D) were used to test the degree and effect of the incorporation of *Mind References principles* into the information representation on each display on participants' task performance. There were eight identical tasks per condition to test the variety of possible situations of a vertical speed representation, four of which were in descent and the other four in ascent. The experimental setup is summarized in the table 8.3.3a (below).

Measurement of duration and accuracy of eight tasks were collected for each participant. Hence, there were 16 data points, eight time data-points (*Time*) per task and eight error data-points (*Score*) per task.

Condi-tions		A Control Numerical representation	B Partial *Mind References* & numerical representation	C Partial *Mind References* & numerical representation	D *Mind References* representation
Features / Tasks		Numbers only	Level-Off-Altitude line & numbers	Vertical-Speed-Triangle of one-minute travel & numbers	All features present
Ascending	1	Middle value			
	2	Minimum value			
	3	Maximum value			
	4	Middle value			
Descending	5	Maximum value			
	6	Middle value			
	7	Minimum value			
	8	Middle value			

Table 8.3.3a: Outline of part I experimental tasks setup

8.3.4 Task and Procedure (Table 8.3.4a):

Upon arrival all participants were asked to read and complete a consent form. The form had basic information about the experiment, the participants' rights and a non-discloser agreement. This form assured that all of the participants had the same information about the experiment.

After signing a consent form, all participants were requested to take a spatial test and an arithmetic test. The experiments where administered in a random order to all participants. These tests where introduced to account for variability in participants' abilities.

In the spatial test pilots had to mentally manipulate a set of two-dimensional objects presented on the computer and provide a written answer to 10 consecutive sets. The arithmetic test had 10 consecutive exercises that involved five-digit subtractions and divisions. The *Total Time* for all 10 tasks and number *Total Errors* were accounted for in the final analysis stage for each of the ability tests. These results allowed having a baseline of participant relative spatial and arithmetic ability. Participants' performance was compared in this experiment and used as a guide to establish whether possessing a better arithmetic or spatial ability influenced participants' performance on experimental displays.

Upon completion of the spatial and arithmetic tests participants' filled a questionnaire about their flying experience and then were randomly assigned to one of four groups (A, B, C or D display condition). They performed the 8 tasks in the randomly allocated condition. Each participant was asked to calculate time to target altitude as fast as they could on each slide with a minimum of errors, then write their answer on a provided form and then proceed to the next screen.

Participants had control over the speed at which they carried out the experiment. When they completed one task, they wrote an answer on an answer sheet and proceeded to the next slide by clicking the button on the screen. The Power Point presentation registered the time spent on each slide (accurate a millisecond) and then presented the next task. These steps were repeated eight times until the final (eighth) slide was presented. Upon completion of the experiment, participants' completed a post-questionnaire expressing their opinion about display conditions, and detailing how they performed the task.

Experimental procedure – part I – 45 minutes
1. Introduction and consent form
2. Random order pre-test of Spatial and Arithmetic ability
3. Flying experience questionnaire
4. Random allocation of A, B, C or D condition display
5. Training on selected condition display
6. Performing 8 tasks on selected condition display
7. Post-questionnaire

Table 8.3.4a: Experimental procedure – part I

8.4 Results–experiment: part (i), between-subject, 4 groups, N = 40

Three types of data-points (table 8.4 below) were collected and analyzed. (1) *Time* per individual task and *Total Time* spent to complete all 8 tasks was measured in minutes, seconds and milliseconds. (2) *Score* was the error per task. *Total Score* was the number of errors in the eight tasks. (3) *Overall Performance* was the result of dividing *Time* over *Score*. Hence the *Total Overall Performance* data-points were the result of dividing *Total Time* over *Total Score*. Data-points were collected for all 40 participants for each individual task (8 tasks per person). All 320 (i.e., 8 tasks multiply by 40 participants) trails were successfully recorded and analyzed.

The same three data-points (Time, Score and Overall Performance) were collected for Spatial and Arithmetic ability tests. However, the ability tests had 400 trails (i.e., 10 tasks multiply by 40 participants) in each test.

The table 8.4 describes the nature of data-point collected in this experiment.

Data-point name	Taken from/Source
Time (Time)	Time taken to complete one task in minutes, seconds, and milliseconds
Score *(Error)*	Full Score for correct answer
Overall Performance *(Time over Score)*	Time taken to complete one task divided by the score for the same task
Total Time	Total time taken to complete a complete 8 tasks in minutes, seconds, and milliseconds
Total Score	Sum of scores for 8 tasks (maximum score is 8)
Total Overall Performance *(Total Time over Total Score)*	*'Total Time'* divided by *'Total Score'*

Table 8.4: Nature of data-points in the experiment

First, more general data-points, such as participants' total performance on eight tasks (*Total Time*, *Total Score* and *Total Overall Performance*) were compared (Figure 8.1, Part 1(i)) to identify whether there was a difference between the four conditions. In Part 1(ii) of the analysis a more in depth analysis was conducted to identify participants' average performance (*Time* per task, *Score* per task and *Overall Performance* per task) on all eight tasks when compared between the four conditions (Figure 8.1, Part 1(ii)). In Part 1(iii) participants' performance on eight individual tasks was compared between the four conditions. In the process of analysis outliers were identified and further analysis eliminated these. Finally, spatial and arithmetic ability test results were correlated with the results of the experimental display conditions. The correlation results showed if there were any dependencies between spatial and arithmetic ability, and the participant's task performance on the displays.

8.5 Analysis of totals over 8 tasks

8.5.1 Total Time (over 8 tasks):

First, a comparison of means of *Total Time* per 8 tasks between the four conditions was performed. The ANOVA test showed the significance of the difference ($F = 5.3$; $p < .004$) between the conditions. Figure 8.5.1a shows this difference. It can be seen that the time taken to complete tasks reduces with each introduction of *Mind References* features onto the display condition. Even though there is more information presented with every condition the mean of *Total Time* (i.e. pilots' time taken to complete all eight tasks) is noticeably reducing. From figure 8.5.1a it is evident that participants' were performing the same task of calculating time to altitude more than twice as fast on display condition D (i.e., display with most Mind Reference features), versus display condition A (i.e., numerical representation only).

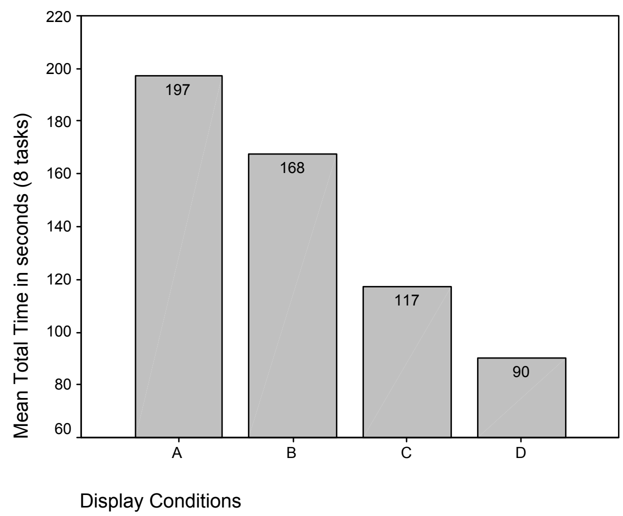


Figure 8.5.1a: Mean of Total Time per 8 tasks on A, B, C and D conditions

To identify which of the four display conditions differed from each other, the Post Hoc Tukey test was performed. The significant differences in *Total Time* performance were between A and C conditions ($p < .050$) and A and D conditions ($p < .005$). As expected, the display condition with most *Mind References* required the least time, in comparison to the display with only a numerical information representation. See Table 8.5.1a below for details.

Multiple Comparisons
Dependent Variable: *Total Time*
Tukey HSD

		Mean Difference (I-J)	**Std. Error**	**Sig.**	**95% Confidence Interval**	
(I) Condition A, B, C or D	(J) Condition A, B, C or D				Lower Bound	Upper Bound
A	B	0:00:29.59	0:00:29.67	.752	-0:00:50.32	0:01:49.50
	C	0:01:19.95	0:00:29.67	**.050**	0:00:00.04	0:02:39.86
	D	0:01:46.92	0:00:29.67	**.005**	0:00:27.01	0:03:06.83
B	A	-0:00:29.59	0:00:29.67	.752	-0:01:49.50	0:00:50.32
	C	0:00:50.36	0:00:29.67	.340	-0:00:29.55	0:02:10.27

	D	0:01:17.33	0:00:29.67	.061	-0:00:02.58	0:02:37.24
C	**A**	-0:01:19.95	0:00:29.67	**.050**	-0:02:39.86	-0:00:00.04
	B	-0:00:50.36	0:00:29.67	.340	-0:02:10.27	0:00:29.55
	D	0:00:26.97	0:00:29.67	.800	-0:00:52.94	0:01:46.88
D	**A**	-0:01:46.92	0:00:29.67	**.005**	-0:03:06.83	-0:00:27.01
	B	-0:01:17.33	0:00:29.67	.061	-0:02:37.24	0:00:02.58
	C	-0:00:26.97	0:00:29.67	.800	-0:01:46.88	0:00:52.94

* The mean difference is significant at the .05 level.

Table 8.5.1a: PostHoc *Total Time* per 8 tasks between tasks and A, B, C and D conditions

8.5.1.1 Outliers:

In the process of analysis the outliers, case 6 from condition A and case 36 from condition D, were identified (Figure 8.5.1.1a below). The outliers were closely examined to determine whether and how these cases affect the results, and whether it was appropriate to continue analysis with these cases being included or excluded.

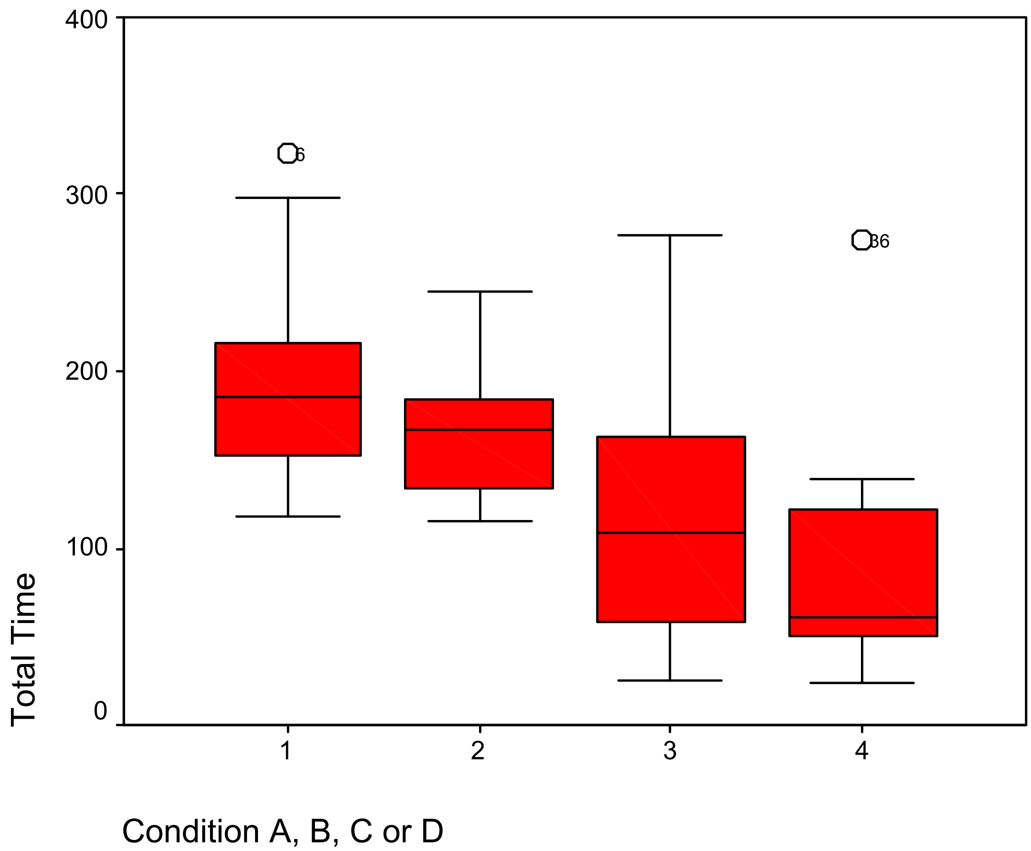


Figure 8.5.1.1a: Outliers in *Total Time*

Case number 6, from display condition A, this participant took the longest (*Total Time* is 0:05:23.10) to complete 8 tasks, which was 1.85 standard deviations (SD = 0:01:07.92) away from group mean (Mean = 0:03:17.32) (Table 8.5.1.1a below). All tasks in the display condition A were numerical. All participants did the Arithmetic test at the beginning of the experiment. The comparison of case 6 *Total Time* performance on Arithmetic test in relation to the experimental group (N=40) is relevant. Arithmetic test results of the whole experimental group (N = 40) show how this particular subject performed in relation to group A and the rest of the 39 participants (Table 8.5.1.1a below).

Later in the chapter (i.e., section Spatial and Arithmetic Ability test results) a full discussion is given of how the *Total Time* on Arithmetic ability test predicts *Total Time* performance on display condition A.

	Case 6		**Case 36**	
	Display Condition A	**Arithmetic test**	**Display Condition D**	**Arithmetic test**
Total Time	05:23.10	06:04.30	04:33.60	07:59.00
Group Mean of *Total Time*	03:17.32	04:26.54	01:30.40	04:26.54
Group Standard Deviation of *Total Time*	01:07.92	01:38.33	01:13.39	01:38.33
***Total Time* is … SD away from the Mean**	1.85	0.99	**2.50**	**2.16**

Table 8.5.1.1a: Outliers details

It was found this participant also scored the highest (above 90th percentile) on *Total Time* in the Arithmetic ability test in his/her group (condition A), and in relation to all 40 participants this participant's score lies between 75th and 90th, being (Arithmetic ability *Total Time* = 0:06:04.30) only one standard deviation (SD = 0:01:38.33) away from group mean (Mean = 0:04:26.54).

This participant did not deviate more than one standard deviation in Arithmetic ability from the rest of the experimental group. Even though case 6 scored high among the participants in condition A, this score lies within one standard deviation from the mean of the whole population. Hence, Case 6 is representative of the whole population (N=40) that was tested. The Arithmetic ability test predicted the participant's time performance on condition A (section 8.9), there are other participants in the whole population that scored as high or higher than case 6. Consequently, this participant's performance is accounted for in the experimental results.

The outlier Case 36 (Figure 8.5.1.1a) from display condition D had a *Total Time* of 0:04:33.60, which is 2,5 standard deviations (01:13.39) away from the group mean (01:30.40) (Table 8.5.1.1a above). After examining a post-questionnaire from this participant the reason of such an extreme score became clear. The participant reported using both methods of calculation, numerical and *Mind Reference* information in condition D while performing the experimental task. This was also observed and noted by the researcher at the time. As this participant did not follow the instruction during the experiment, the result of this was that the participant was excluded from the analysis. This participant performed the task distinctly differently to all other participants in this condition.

8.5.1.2 Total Time without Outlier (over 8 tasks):

Once the outlier (Case 36) is removed from the analysis, the significant difference becomes even higher ($F = 8.6$; $p < .0001$) in *Total Time* between the four conditions. Figure 8.5.1.2a below shows the trend of *Total Time* reducing markedly starting high on A display condition, becoming low on D. Pilots performed tasks in condition D 2.8 times faster than in condition A.

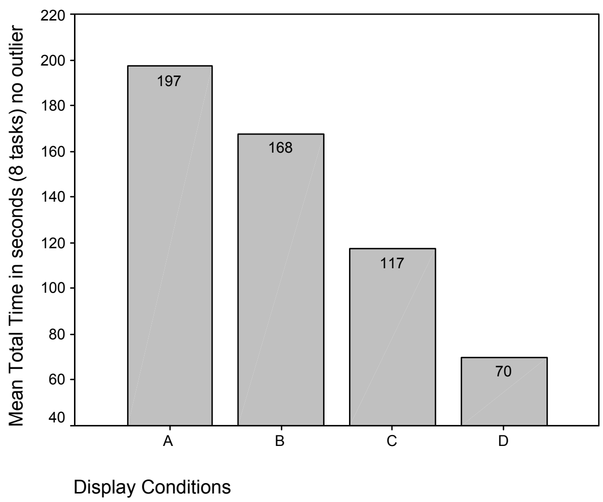


Figure 8.5.1.2a: Mean of *Total Time* per 8 tasks on A, B, C and D conditions with outlier Case 36 removed

The Post Hoc Tukey analysis on *Total Time* without the outlier (N=39) shows that the significant difference between the four display conditions in the Analysis of Variance was due to the significant difference between condition C and A ($p < .022$), D and A (p < ..0001) and condition B and D ($p < .005$) (Table 8.5.1.2a). From this result it was considered appropriate to find out whether participants' accuracy suffered due to the rate at which they performed the test.

Multiple Comparisons
Dependent Variable: *Total Time*
Tukey HSD

		Mean Difference (I-J)	**Std. Error**	**Sig.**	**95% Confidence Interval**	
(I) Condition A, B, C or D	(J) Condition A, B, C or D				Lower Bound	Upper Bound
A	B	0:00:29.59	0:00:26.31	.677	-0:00:41.38	0:01:40.56
	C	0:01:19.95	0:00:26.31	**.022**	0:00:08.98	0:02:30.92
	D	0:02:07.28	0:00:27.03	**.000**	0:00:54.37	0:03:20.19
B	A	-0:00:29.59	0:00:26.31	.677	-0:01:40.56	0:00:41.38
	C	0:00:50.36	0:00:26.31	.241	-0:00:20.61	0:02:01.33
	D	0:01:37.69	0:00:27.03	**.005**	0:00:24.78	0:02:50.60
C	**A**	-0:01:19.95	0:00:26.31	**.022**	-0:02:30.92	-0:00:08.98
	B	-0:00:50.36	0:00:26.31	.241	-0:02:01.33	0:00:20.61
	D	0:00:47.33	0:00:27.03	.314	-0:00:25.58	0:02:00.24
D	**A**	-0:02:07.28	0:00:27.03	**.000**	-0:03:20.19	-0:00:54.37
	B	-0:01:37.69	0:00:27.03	**.005**	-0:02:50.60	-0:00:24.78

	C	-0:00:47.33	0:00:27.03	.314	-0:02:00.24	0:00:25.58

* The mean difference is significant at the .05 level.

Table 8.5.1.2a: PostHoc *Total Time* per 8 tasks between tasks and A, B, C and D conditions without outlier

8.5.2 Total Score (over 8 tasks):

Participant' performance on each display was graded as follows: '1' being the highest score per task, making '8' the highest score for a total of 8 tasks. The comparison of *Total Score* means shows that there was a significant difference (F = 4.3; p < .011) between the four conditions.

The comparison of *Total Score* means, as shown on the graph (Figure 8.5.2a), shows the reverse trend from the one of *Total Time* (Figure 8.5.1a). This suggests that participants' made fewer errors (i.e. higher score) on the (D) condition display in comparison to the other conditions.

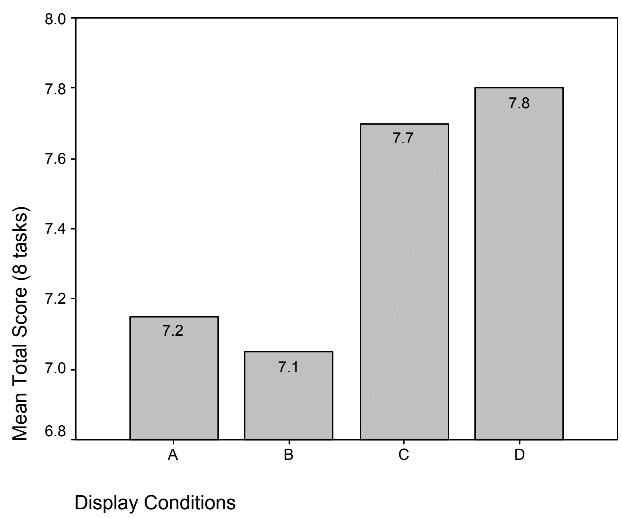


Figure 8.5.2a: Mean of *Total Score* per 8 tasks on A, B, C and D conditions

Although there was a significant difference between the four display conditions in the *Total Score*, the Post Hoc Tukey test calculations shows the significant difference (SE = .26; p < .032) only exists between display condition B (mean 7.05) and D (mean 7.8). At this point it was considered appropriate to investigate whether excluding the outlier (case 36) would influence the overall comparison between the conditions.

Multiple Comparisons
Dependent Variable: *Total Score*
Tukey HSD

		Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
(I) Condition A, B, C or D	(J) Condition A, B, C or D				Lower Bound	Upper Bound
A	B	.1000	.26034	.980	-.6012	.8012
	C	-.5500	.26034	.168	-1.2512	.1512
	D	-.6500	.26034	.077	-1.3512	.0512
B	A	-.1000	.26034	.980	-.8012	.6012

	C	-.6500	.26034	.077	-1.3512	.0512
	D	-.7500	.26034	**.032**	-1.4512	-.0488
C	A	.5500	.26034	.168	-.1512	1.2512
	B	.6500	.26034	.077	-.0512	1.3512
	D	-.1000	.26034	.980	-.8012	.6012
D	A	.6500	.26034	.077	-.0512	1.3512
	B	.7500	.26034	**.032**	.0488	1.4512
	C	.1000	.26034	.980	-.6012	.8012

* The mean difference is significant at the .05 level.

Table 8.5.2a: PostHoc *Total Score* per 8 tasks between tasks and A, B, C and D conditions

8.5.2.1 Total Score without Outlier (over 8 tasks)

The analysis of *Total Score* between the four display conditions without the outlier effected the results, but not greatly. The comparison table 8.5.2.1a shows a slight increase in condition D. The same can be seen from the graph 8.5.2.1a below when compared with the earlier graph (Figure 8.5.2a above) with the outlier included in the analysis.

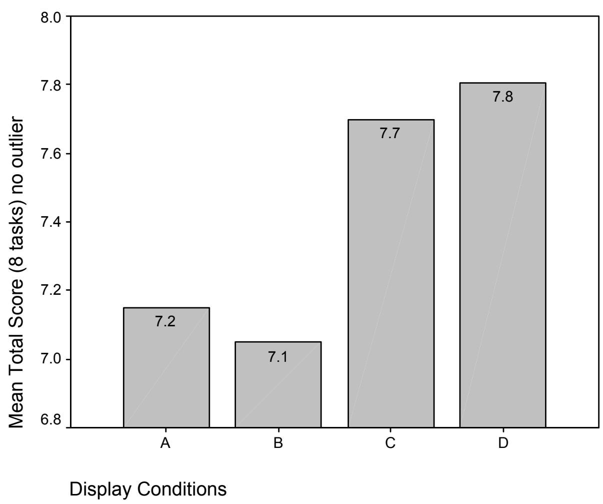


Figure 8.5.2.1a: Mean of *Total Score* per 8 tasks on A, B, C and D conditions with outlier Case 36 removed

Display condition s	Mean *Total Score* for 8 tasks N=40	Mean *Total Score* for 8 tasks no outlier N=39
A	7.1500	7.1500
B	7.0500	7.0500
C	7.7000	7.7000
D	**7.8000**	**7.8056**

Table 8.5.2.1a: Mean of *Total Score* per 8 tasks on A, B, C and D conditions with outlier Case 36 removed

The Post Hoc Tukey analysis on *Total Score* without the outlier shows that same results as in the *Total Score* analysis with the outlier (Table 8.5.2a).

8.5.3 Total Overall Performance (over 8 tasks)

The *Total Overall Performance* was calculated by dividing an average of the *Total Time* for the 8 tasks by the average of the *Total Score* for the 8 tasks (as described above in Table 8.5). This newly generated score (*Total Time* over *Total Score*) was calculated to account for pilots overall performance on the display conditions, accounting for time and error in one data point, eliminating the trade-off factor (i.e. if participants take longer to achieve a more accurate score, or make a guess to achieve a faster performance).

When means of the *Total Overall Performance* were compared between the four conditions through Analysis of Variance (df = 39), it showed the significant difference (F = 6.9; p< .001) between the display conditions.

Total Overall Performance trend (Figure 8.5.3a) is similar to that of the *Total Time* from Figure 8.5.1.2a., indicating *Total Overall Performance* was improving as *Mind Reference* information was being introduced onto the display.

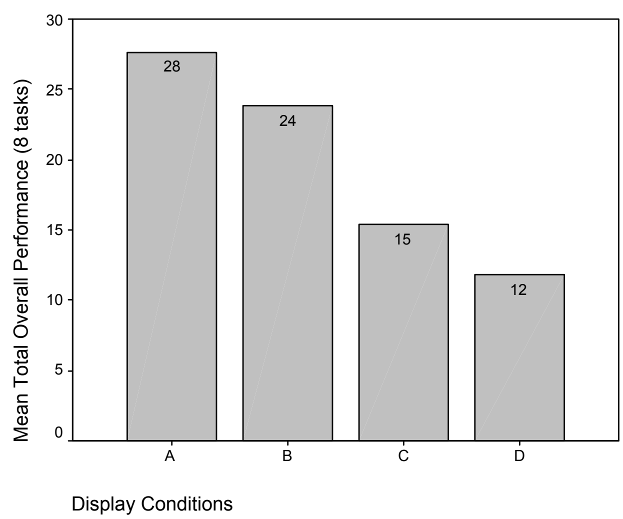


Figure 8.5.3a: Mean of *Total Overall Performance* per 8 tasks on A, B, C and D conditions

Even though more information is presented from A to B to C and finally to D, the time to calculate and the accuracy (*Score*) combined improves. The difference in *Total Overall Performance* is over 2 times better in conditions D, than it is in A, as it can be seen from figure 8.5.3a above.

The Post Hoc Tukey test calculations showed a significant difference between A and C; A and D; and B and D. Table 8.5.3a below highlights these results.

The interesting point that the Post Hoc Tukey test highlights is that the mean difference in *Total Overall Performance* is significant when the triangle with reference-lines is introduced into the display in condition C (Figure 8.2.2c) and D (Figure 8.2.2d).

Difference between *Total Overall Performance*	Significance p < …	Standard Error	Mean Difference

means of:			
A & D display conditions	0.002	3.94	15.85
A & C display conditions	0.019	3.94	12.24
B & D display conditions	0.021	3.94	12.04

Table 8.5.3a: Significant Difference of *Total Overall Performance* between A, B, C and D conditions

These results were further investigated to ascertain whether these Total Overall Results were influenced by the inclusion of the outlier (Case 36, Figure 8.5.1.1a).

8.5.3.1 Total Overall Performance without Outlier (over 8 tasks)

The comparison of *Total Overall Performance* means between the four conditions through Analysis of Variance (df = 38) without the outlier shows that there is a significant difference (F = 10.6; p < ..0001) between the four conditions demonstrating the inclusion of the outlier had influenced the previous results.

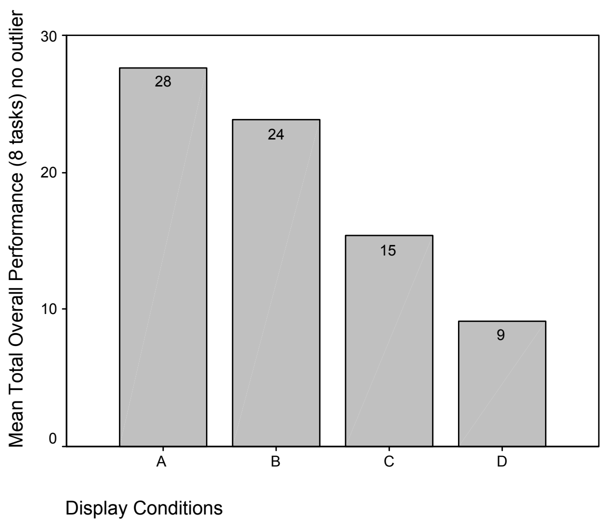


Figure 8.5.3.1a: Mean of *Total Overall Performance* per 8 tasks on A, B, C and D conditions with outlier Case 36 removed

When the outlier (case 36) in condition D was eliminated the difference in *Total Overall Performance* between A and D conditions was seen to be three times greater on condition D versus the display condition A (Figure 8.5.3.1a).

The Post Hoc Tukey test highlighted similar results for the *Total Overall Performance* with this outlier accounted for, apart from showing a slight increase in the significant difference between the means. Again the display condition D produced a better performance.

These results showed participants' performance on a total of 8 tasks was always better on condition D. However, it was considered that extra analysis between mean pilots performance per task, per condition compared between four conditions was needed to ascertain whether on average participants' did an individual task better on condition D than on other conditions.

8.6 Analysis per single task between four conditions

The analysis of the mean group (A, B, C and D) performance per task was performed to determine whether, on average, participants performed better on the display condition with most features designed using the Mind Reference framework in comparison to the three other conditions. Wherein Condition A had no features designed using the framework (i.e., A condition – numerical presentation, Figure 8.2.2a) and condition B (Figure 8.2.2b) and C (Figure 8.2.2c) had partial implementations of the features designed using the Mind Reference framework.

8.6.1 Time per single task between four conditions

As it was anticipated, the result of the mean *Time* per individual task between the four conditions showed similar results to the *Total Time* for all 8 tasks. There was a significant difference ($p < .004$) between four conditions. The Figure 8.6.1a below illustrates the gradual reduction of time taken to perform an individual task in each condition. *Time* per task starting at 25 (plus or minus 8) seconds on condition A and going progressively down through display conditions B and C with the lowest time of 11 (plus or minus 2,5) on condition D display.

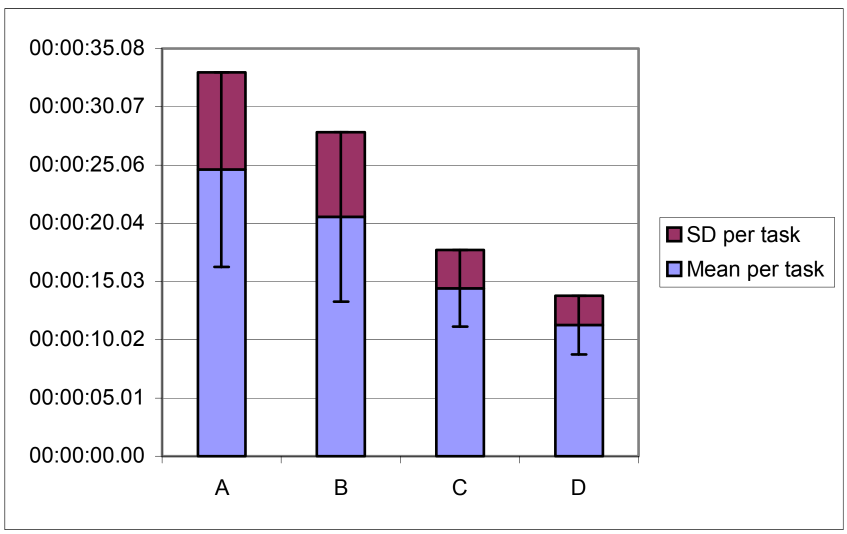


Figure 8.6.1a: Mean *Time* per task with one standard deviation in all conditions

The Post Hoc Tukey analysis on Mean *Time per task* (N=39) showed that there was a significant difference between display conditions C and A ($p < .044$), and D and A ($p < .005$). Next, this result was further investigated without outliers.

8.6.1.1 Time per single task between four conditions without outlier

The table below highlights a large difference in the *Time* per task between conditions A and D. Now that the outlier has been eliminated from the analysis the mean *Time* per task in condition D is 2.8 times less than the participants' mean *Time* per single task performance on display condition A, where the standard deviation is reduced by five times (Figure 8.6.1.1a and Table 8.6.1.1a). This signifies that the participants in condition D performed individual tasks with less variance in time than on condition A.

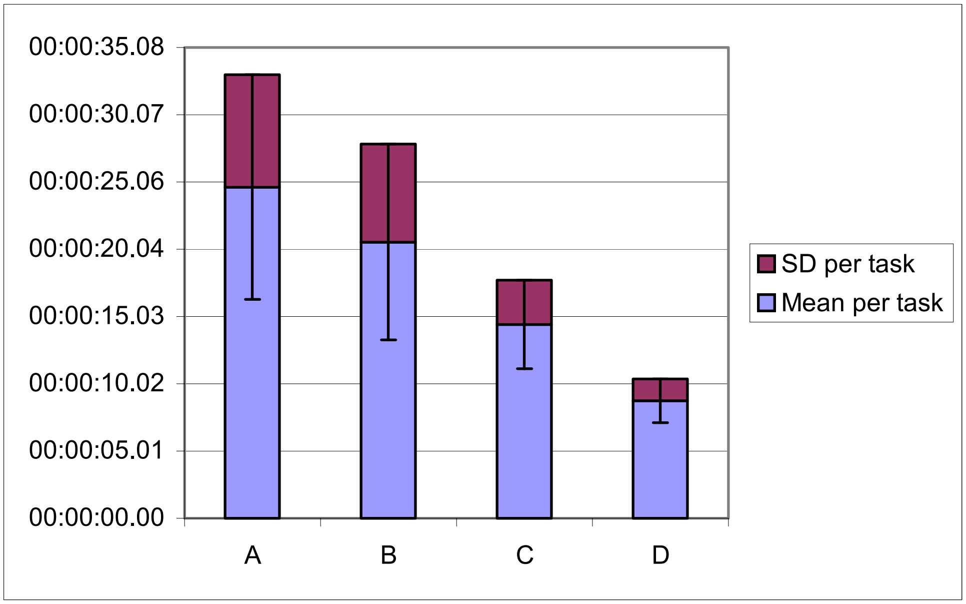


Figure 8.6.1.1a: Mean *Time* per task with one standard deviation in all conditions with outlier Case 36 removed

		Mean *Time* per condition per task			
		A	**B**	**C**	**D**
With outlier	**Mean**	00:00:24.67	00:00:20.58	00:00:14.45	**00:00:11.30**
	SD	00:00:08.37	00:00:07.29	00:00:03.31	00:00:02.53
Without outlier	**Mean**	00:00:24.67	00:00:20.58	00:00:14.45	**00:00:08.75**
	SD	00:00:08.37	00:00:07.29	00:00:03.31	00:00:01.63

Table 8.6.1.1a: Comparison of means per single between conditions with and with outlier Case 36 removed

Once the outlier (case 36) was eliminated from the analysis there was an overall increase in the significance of the mean difference ($F(3,36) = 8.508$; $p <$ ..0001) between conditions.

The Post Hoc Tukey analysis on Mean *Time per task* (N=39) showed a significant difference between display conditions A and C ($p < .019$), A and D ($p <$ ..0001), as well as an additional significant difference between conditions B and D ($p < .007$).

From these results it was considered appropriate to find out whether participants' accuracy, on average, per condition suffered due to the rate at which they performed the test.

8.6.2 Score per single task between four conditions

The mean *Score* per individual task between the four conditions indicated that the participants' accuracy was similar to the result of the *Total Score* per eight tasks (8.5.2a). The GLM Repeated Measures Test showed that there was a significant difference between the four conditions in *Score* per individual task ($F(3,36) = 4.25$; $p < .011$).

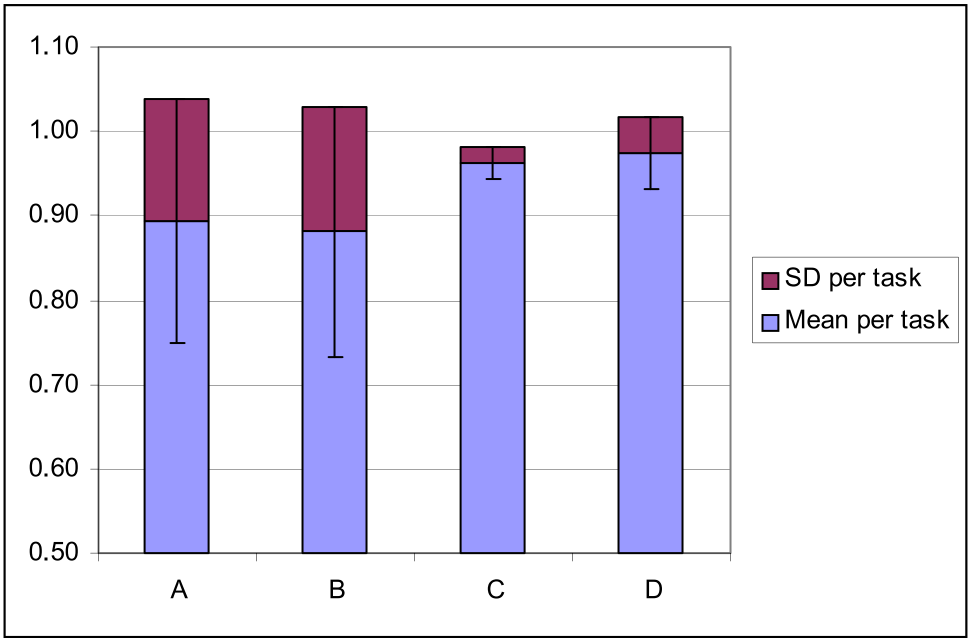


Figure 8.6.2a: Mean *Score* per task with one standard deviation in all conditions

The results showed participants' provide a significantly ($p < .032$) more accurate answer on condition D, than B (Figure 8.6.2a) as the PostHoc Tukey test showed.

8.6.2.1 Score per single task between four conditions without an outlier

This analysis performed without the outlier again did not show any improvement in participant accuracy performance. This is because, as discussed in the outlier section earlier, case 36 traded time for accuracy, this made his/her scores high, but increased *Time* spent on each task. However, this did not affect the test results. There was still a significance difference ($F(3,36) = 4.04$; $p < .014$). The PostHoc Tukey test too showed the significant difference between the same conditions B and D ($p < .041$).

8.6.3 Overall Performance **per single task between four conditions**

To close this part of the section the results of average group *Overall Performance per single task* between four conditions are described. The Overall Performance is a score that takes into account both the Time participants' took to complete the task and the number of correct responses participants' gave.

From these results it was seen that Mean *Overall Performance* per individual task between the four conditions, similarly to the *Total Overall Performance* for all 8 tasks (Figure 8.5.3a), is reducing (Figure 8.6.3a). *Overall Performance* per task starts as high as 26 with a Standard Deviation of plus or minus 7 on condition A and progressively decreases down through display conditions B and C with the lowest of 12. The display condition has lower Standard Deviation out of four conditions (SD = 3), meaning that there is a smaller variation in participants' average performance per task.

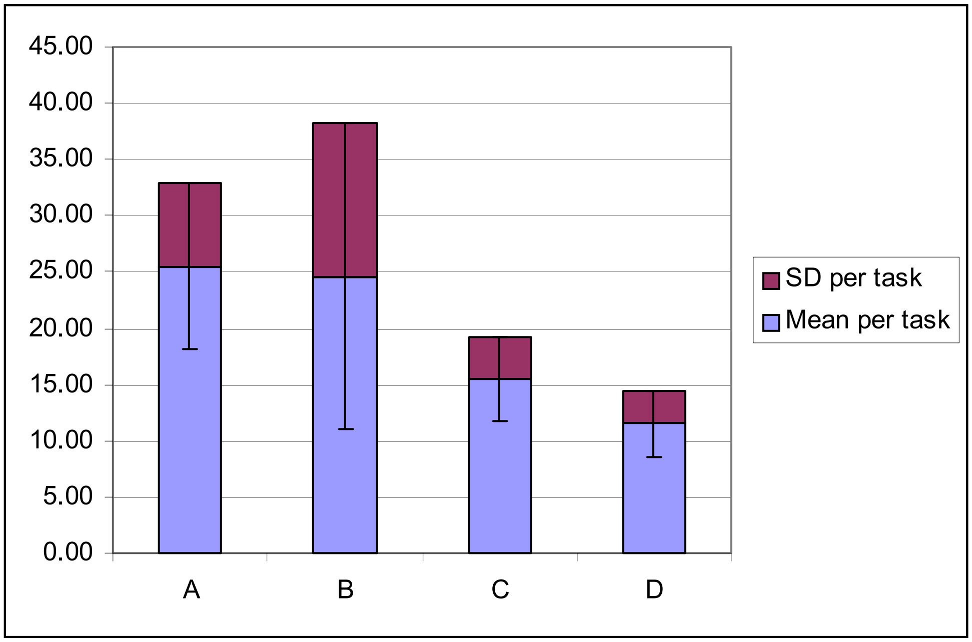


Figure 8.6.3a: Mean *Overall Performance* per single task with one standard deviation in all conditions

The GLM Repeated Measures test showed that there was a significant difference between the four conditions in *Overall Performance* per individual task ($F(3,36) = 4.95$; $p < .006$). The PostHoc Tukey test showed a significant difference between conditions A and D ($p < .015$) and B and D ($p < .024$).

8.6.3.1 Overall Performance per single task between four conditions without outlier

The graph (Figure 8.6.3.1a) and the Table 8.6.3.1a below highlight the great difference in the *Overall Performance* per task between conditions A and D. Now that the outlier is eliminated from the analysis the mean *Overall Performance* per task in condition D (Table 8.6.3.1a) is almost 3 times less than the participants' mean *Overall Performance* per single task performance on display condition A, with the standard deviation reduced by almost 4 (3.834) times.

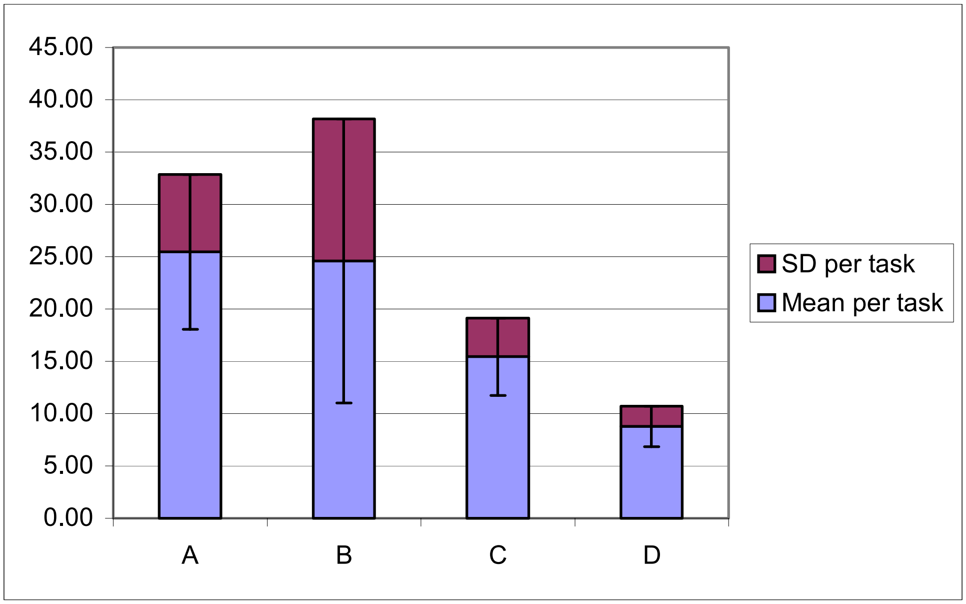


Figure 8.6.3.1a: Mean *Overall Performance* per single task with one standard deviation in all conditions without an outlier

	Mean *Overall Performance* per condition per single task				
		A	**B**	**C**	**D**
With outlier	**Mean**	25.46	24.60	15.44	**11.51**
	SD	7.40	13.56	3.72	2.88
Without outlier	**Mean**	25.46	24.60	15.44	**8.76**
	SD	7.40	13.56	3.72	1.93

Table 8.6.3.1a: Comparison of means per single between conditions with and with outlier Case 36 removed

The GLM Repeated Measures test showed a significant difference ($p < ..0001$) between conditions. The PostHoc Tukey test showed the significant difference between the same conditions A and D ($p < .001$), and B and D ($p < .002$), but with much higher significance.

These results show participants' average task (on total of 8 tasks) performance between the four conditions was always better on condition D. However, it was considered that extra analysis was needed to identify between which out of eight tasks there was a difference in the four conditions. This was required to identify which presentations in the total of the eight tasks was producing the best and the worst performance.

8.7 Analysis per task between 8 tasks

The analysis of the mean performance per individual task was compared between four conditions to determine on which out of eight type of presentations participants' performed better. It was expected that even though the arithmetic difficulty of the tasks increased, participants' would still perform better on the display condition with the most features designed using the Mind Reference framework (i.e., D condition - Figure 8.2.2d) in comparison to the three other conditions (i.e., A condition – numerical presentation – Figure 8.2.2a; condition B – Figure 8.2.2b; C – Figure 8.2.2c).

8.7.1 Time per task between 8 tasks

This section discusses how the variety of possible representations of vertical speed as a *Mind Reference* feature affected participant' (i.e. pilots in these experiments) performance in the eight tasks (four in descent and four in ascent representations). The end of this section also discusses participants' comments and suggestions for display design improvement as collected in the post-experiment questionnaire.

The data collected allowed a comparison of the individual mean *Time per task* between the four conditions. An Analysis of Variance (Table 15) showed a significant difference in tasks 3 ($F(3,36) = 7.3$; $p< .001$), 4 ($F(3,36) = 4.3$; $p< .010$), 5 ($F(3,36) = 5.6$; $p< .003$) and 8 ($F(3,36) = 5.3$; $p< .004$) between four conditions.

Figure 8.7.1a highlights the difference in *Time per task* between all four display-conditions graphically. Display condition D allowed participants' to produce the better *Time* performance on almost all tasks out of all four conditions.

As discussed earlier, the display conditions A and B had none and minimal amount of *Mind Reference* information present respectively. As it can be seen from Figure 8.7.1a, participants' still performed better with some level of *Mind Reference* information on condition B versus condition A (i.e., A - purely numerical information presentation). The same tendency is true for conditions C and D, where condition D (with maximum *Mind Reference* information) allowed pilots to perform slightly better, apart from one task (5). Results on task 5 are discussed further in the next section that discusses the outlier in the data. *Time pre task* performance on condition C was slightly better (difference of 01.67 seconds) than on condition D. This is attributed to an outlier in a group D, which was discussed earlier in this chapter, which was removed in further analysis and the results are discussed in the next section 8.7.1.1.

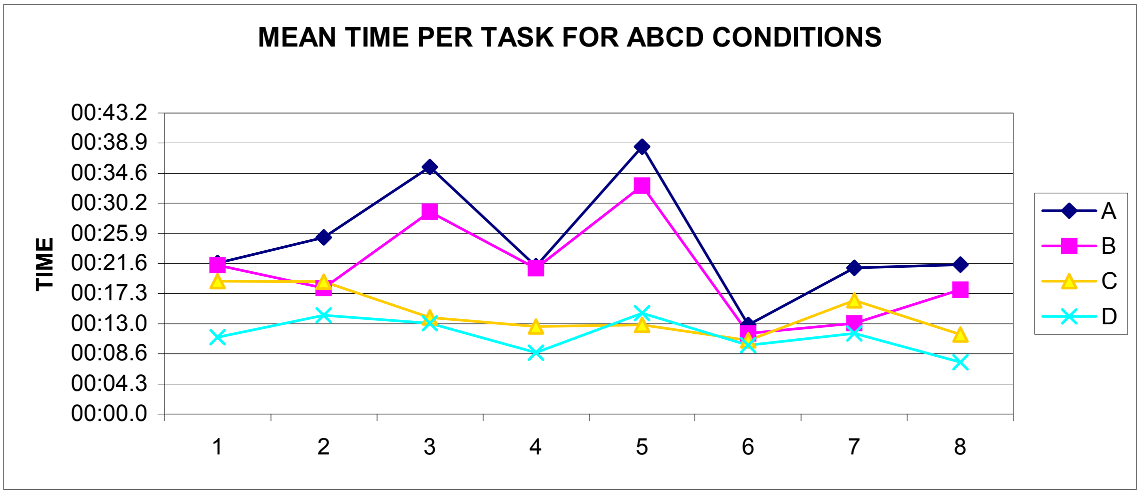


Figure 8.7.1a: Mean *Time per task* between A, B, C and D conditions

Table 8.7.1a below shows the same trend as the figure 8.7.1a above. The table, however, shows further details of how *Time per task* reduces from A to D conditions and from task 1 to task 8.

Descriptives

	Mean *Time* per condition per task				
Task	**A**	**B**	**C**	**D**	**Trend – *Time* reducing**
Task 1	**0:00:21.71**	0:00:21.38	0:00:19.10	**0:00:11.04**	
Task 2	0:00:25.38	0:00:18.10	0:00:18.96	0:00:14.15	
Task 3	0:00:35.48	0:00:29.00	0:00:13.90	0:00:13.00	
Task 4	0:00:21.21	0:00:20.93	0:00:12.53	0:00:08.82	
Task 5	0:00:38.34	0:00:32.77	0:00:12.81	0:00:14.48	
Task 6	0:00:12.77	0:00:11.55	0:00:10.57	0:00:09.87	
Task 7	0:00:20.98	0:00:13.03	0:00:16.32	0:00:11.60	
Task 8	**0:00:21.45**	0:00:17.87	0:00:11.38	**0:00:07.40**	
Trend – *Time* reducing					
Mean	**00:00:24.67**	**00:00:20.58**	**00:00:14.45**	**00:00:11.30**	
SD	**00:00:08.37**	**00:00:07.29**	**00:00:03.31**	**00:00:02.53**	

Table 8.7.1a: Mean *Time* per task in all conditions

When the difference in *Time* performance was compared on the first (task 1) and the last (task 8) task across all participants' in all display conditions, although there was a significant between the four conditions ($t = 2.48$; $p < .035$), the improvement was only on the condition D. There was practically (less then half a second) no improvement between the same tasks on condition A, but on the display condition D there was an improvement of 3.5 seconds. Figure 6 highlights the differences graphically between the mean tasks *Time* in condition A and D.

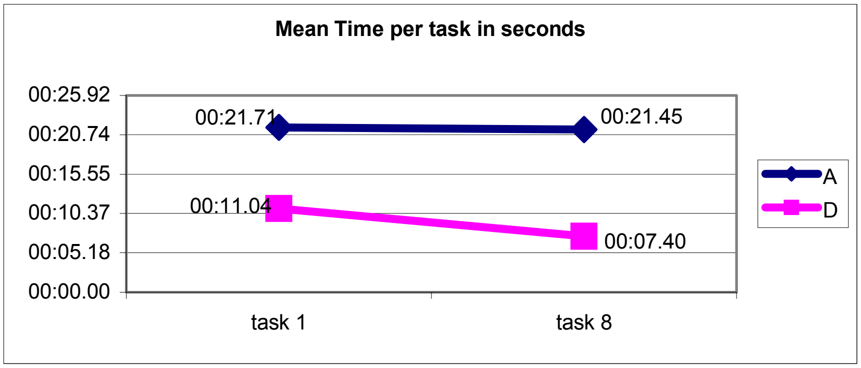


Figure 8.7.1b: Comparison of mean *Time* per single task between Task 1 and 8

Therefore, it was considered important to examine on which out of eight tasks there was a difference in performance and examine why this is the case. Three points can be extracted from Figure 8.7.1a above. (1) Participants' *Time* performance per task fluctuates in a similar way on display conditions A and B. In tasks 3 and 5 participants *Time* per task in conditions A and B increased compared to the rest of the tasks. On conditions C and D the change is less noticeable. In tasks 3 and 5 the vertical speed value was expressed as a maximum value, compared to other tasks these were the most arithmetically demanding tasks of all presented to participants. However participants still performed better on conditions C and D. On task 6, however, all display conditions performed similarly low in *Time* per task, but the lowest *Time* was still on display condition D. (2) Participants' performance was fairly consistent on display conditions C and D, where most of the *Mind Reference* principles were implemented in the design. (3) Display condition D, however, supported the most consistent performance, the mean was 0:01:30.40 with Standard Deviation of 0:01:13.49, which was lower than on condition C.

Depending on the type of vertical speed task value introduced (maximum value – on tasks 3 (Figure 8.7.1e) and 5 (Figure 8.7.1g), middle value – on tasks 1 (Figure 8.7.1c), 4 (Figure 8.7.1f), 6 (Figure 8.7.1h) and 8 (Figure 8.7.1j), minimum value – on tasks 2 (Figure 8.7.1d) and 7 (Figure 8.7.1i)) in both descending and ascending task scenarios, the participants performed better on displays where the middle vertical speed task value or the minimum task value was introduced. Table 8.3.3, at the beginning of the chapter, summarises the experimental setup and shows the sequence of task values in the scenarios presented to participants.

Comparison of the various representations of vertical-speed-triangle (maximum, middle and minimum values) in the four display conditions was made to determine on which task participants gave the best *Time* performance. Tukey PostHoc test showed the significant differences, which are summarised in table 8.7.1b below.

Task	Vertical Speed representation	Display Condition	Significance p < …	Standard Error	Mean Difference
3 task	**Maximum value**	C and A	.004	0:00:05.86	-0:00:21.58
		D and A	.003	0:00:05.86	-0:00:22.48

		D and B	.046	0:00:05.86	-0:00:16.00
4 task	**Middle value**	D and A	.028	0:00:04.21	-0:00:12.39
		D and B	.032	0:00:04.21	-0:00:12.11
5 task	**Maximum value**	C and A	.011	0:00:07.68	-0:00:25.53
		D and A	.018	0:00:07.68	-0:00:23.86
8 task	**Middle value**	D and A	.005	0:00:03.90	-0:00:14.05

Table 8.7.1b: PostHoc of mean *Time* per task between tasks and A, B, C and D conditions

The Tukey PostHoc test results showed that task 3 (Figure 8.7.1e) and 5 (Figure 8.7.1g) with a task scenario of maximum value of vertical speed triangle appeared to have a significant difference (ANOVA, $F(3,36) = 7.29$, $p < .001$ and $F(3,36) = 5.62$, $p < .003$ respectively, see table 8.7.1b above). The difference in mean *Time* between conditions A and D, on tasks 3 and 5, were more than double. Similar results were seen in the tasks with the middle value of vertical speed, tasks 4 (Figure 8.7.1f) and 8 (Figure 8.7.1j) (ANOVA, $F(3, 36) = 4.33$, $p < .010$ and $F(3, 36) = 5.25$, $p < .004$)

Task 6 appeared to have the least amount of difference in mean *Time* between all four conditions (ABCD). This could be attributed to a simpler arithmetic task in this scenario compared to the rest of the task scenarios (Figure 8.7.1h).

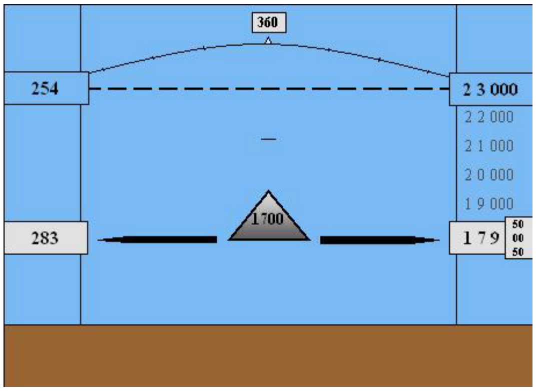


Figure 8.7.1c: Display for task 1

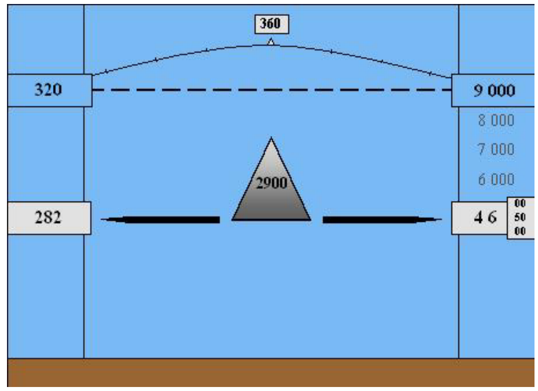


Figure 8.7.1d: Display for task 2

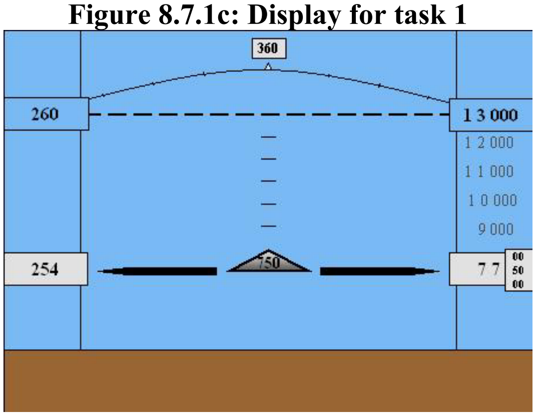


Figure 8.7.1e: Display for task 3

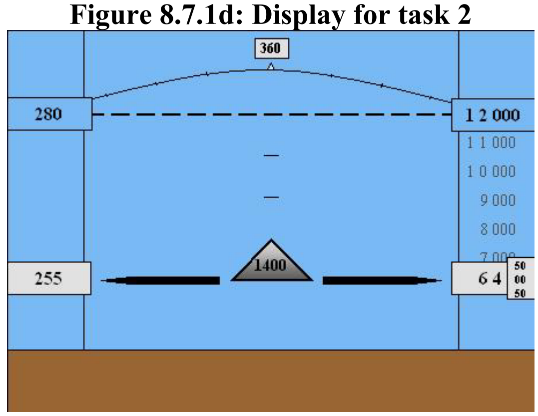


Figure 8.7.1f: Display for task 4

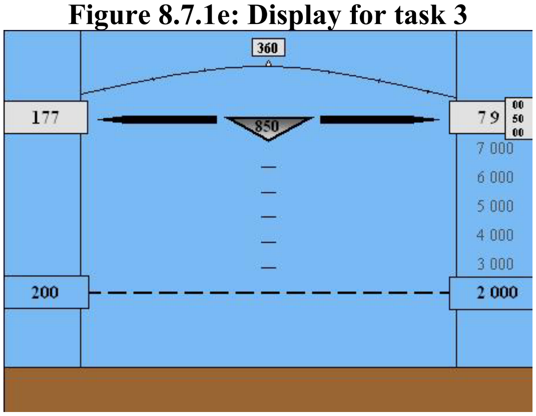


Figure 8.7.1g: Display for task 5

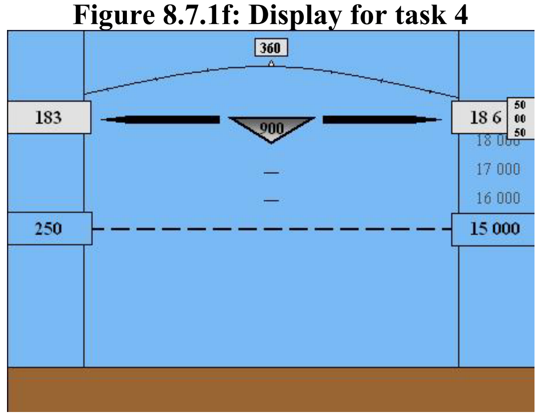


Figure 8.7.1h: Display for task 6

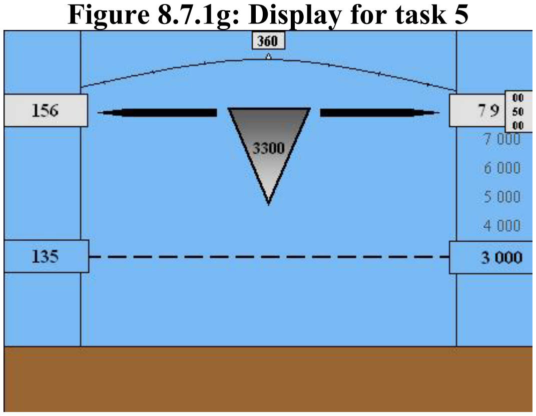


Figure 8.7.1i: Display for task 7

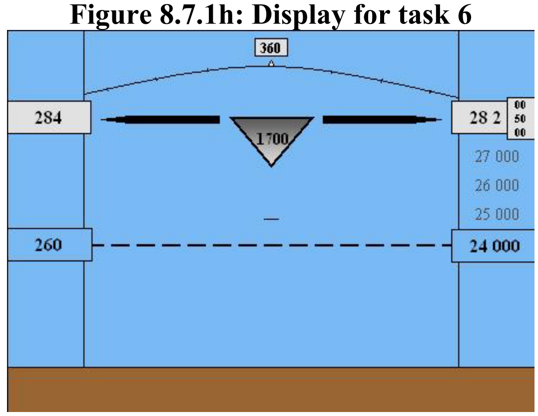


Figure 8.7.1j: Display for task 8

8.7.1.1 Time per task without outlier, N = 39

Task 5 was the only task where participants' performance was worse than on condition C. This required a close examination of the *Time* data-points of individual participants on task 5. This revealed that there was in outlier, case 36, in condition D. This participant has been previously discussed; the participant performed all tasks (reported in the post-questionnaire) using both methods of calculation, numerical and *Mind Reference* information in condition D. Eliminating this outlier showed a greater significant difference, and also showed significance to one more additional task (task 2) (Figure 8.7.11a).

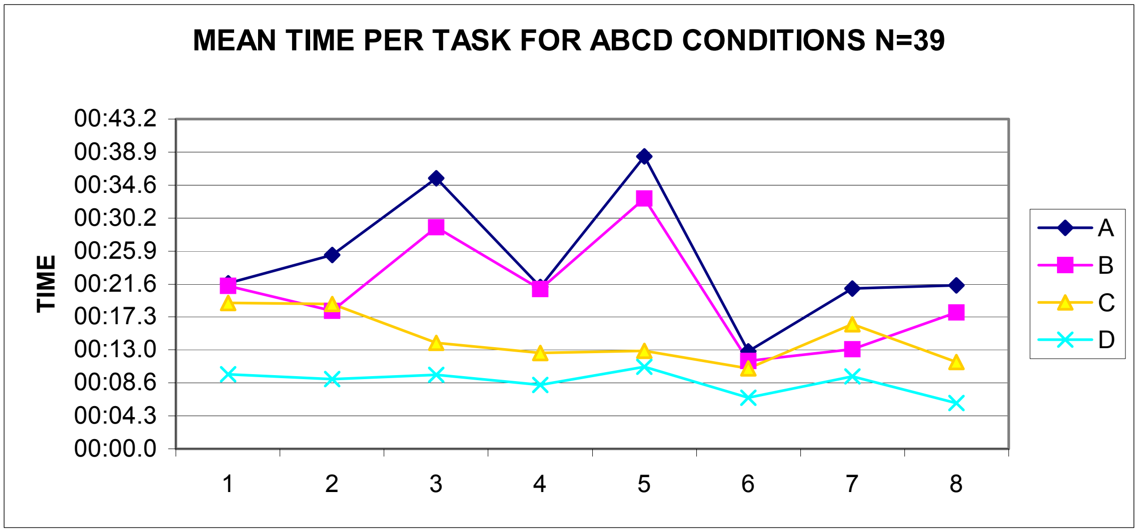


Figure 8.7.1.1a: *Time* per task between conditions A, B, C and D (N = 39)

PostHoc analysis showed there is always a significant difference between conditions A and D in tasks 2 ($p > .031$), 3 ($p >$ ..0001), 4 ($p > .028$), 5 ($p > .004$) and 8 ($p > .002$). Table 8.7.1.1a below highlights further the significant differences between conditions A and C in tasks 3 and 5; between conditions B and D in tasks 3, 4, 5 and 8; and between condition A and C in tasks 3 and 5. These results showed that even when not all Mind Reference features are implemented on the display, such as in the condition C, participants' performance is still faster than on a purely numerical display, such as the condition A display.

Task	Display Condition	Significance p < …	Standard Error	Mean Difference
2 task	D and A	.031	0:00:05.59	-0:00:16.24
3 task	C and A	.002	0:00:05.45	-0:00:21.58
	C and B	.042	0:00:05.45	-0:00:15.10
	D and A	.000	0:00:05.60	-0:00:25.75

	D and B	.008	0:00:05.60	-0:00:19.27
4 task	D and A	.028	0:00:04.37	-0:00:12.85
	D and B	.033	0:00:04.37	-0:00:12.57
5 task	C and A	.007	0:00:07.31	-0:00:25.53
	C and B	.046	0:00:07.31	-0:00:19.96
	D and A	.004	0:00:07.51	-0:00:27.61
	D and B	.029	0:00:07.51	-0:00:22.04
8 task	D and A	.002	0:00:03.93	-0:00:15.44
	D and B	.023	0:00:03.93	-0:00:11.86

Table 8.7.1.1a: PostHoc of mean *Time* per task between tasks and A, B, C and D conditions (N=39) with outlier Case 36 removed

From this result it was considered appropriate to find out whether the participants' accuracy suffered due to the rate at which they performed the individual tasks.

8.7.2 Score per task between 8 tasks

As shown in the ANOVA table … below the mean *Score* per task only differed significantly in tasks 3 ($p > .010$) and 5 ($p > .001$). This result was encouraging, because these were the most difficult task scenarios for the participants to perform (i.e. maximum vertical speed value). Despite the fact that participants had as much time as they needed, they still performed significantly poorly on displays with minimal or no *Mind Reference* design features and performed better on displays with the maximum *Mind Reference* features presented (i.e. condition D). Also these two tasks were commented on in the post-questionnaire, as being 'difficult' to count. Suggestions for further improvements on these displays will be considered in the discussion section.

Figure 8.7.2a highlights how mean *Score* does not fluctuate on display condition D versus A and B conditions. The display condition D appeared to help pilots to produce consistent performance on all task throughout the experiment.

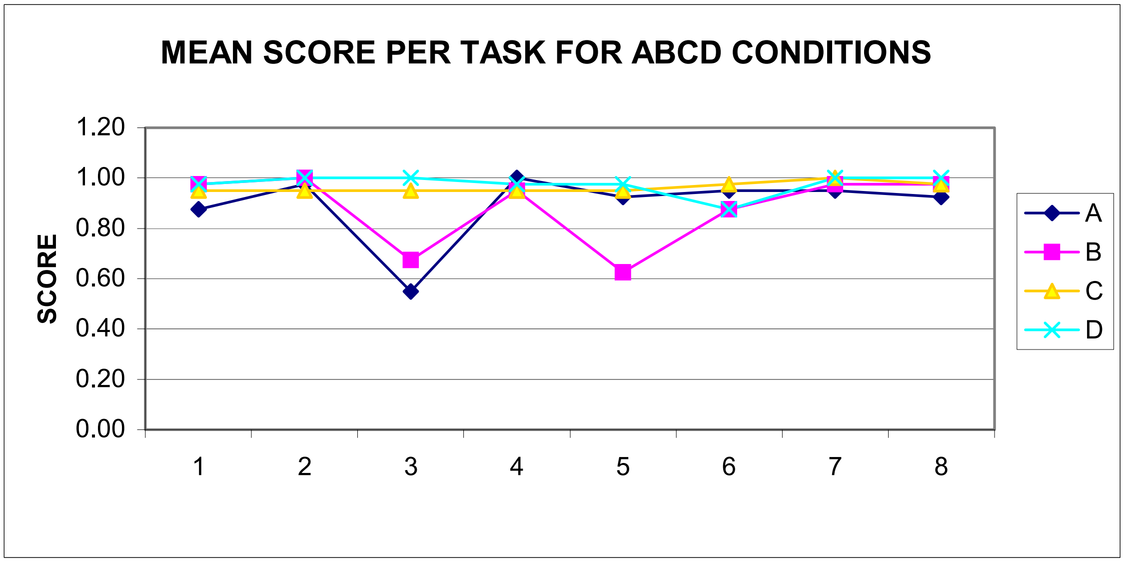


Figure 8.7.2a: *Score* per task between conditions A, B, C and D

A PostHoc analysis showed there were significant differences between conditions in tasks 3 and 5. Table 8.7.2a below highlights the significant differences.

Task	Display Condition	Significance p < …	Standard Error	Mean Difference
3 task	C and A	.045	.146	.400
	D and A	.020	.146	.450
5 task	B and A	.007	.086	-.300
	C and B	.003	.086	.325
	D and B	.001	.086	.350

Table 8.7.2a: PostHoc of mean *Score* per task between tasks and A, B, C and D conditions

8.7.2.1 Score per task without outlier, N = 39

When the analysis of the data was performed without the outlier (case 36) it showed similar differences in the *Score* per task, for the same tasks as in the analysis with the outlier, however, there were greater differences in task 3 ($p > .013$) and task 5 ($p > ..0001$).

The figure 8.7.2.1a below confirms and highlights a slight improvement in condition D display on tasks 3 and 5, making accuracy performance on display condition D more consistent across all 8 tasks.

The Post Hoc Tukey analysis also showed similar differences in tasks 3 and 5 in the same conditions as when the outlier was part of the analysis.

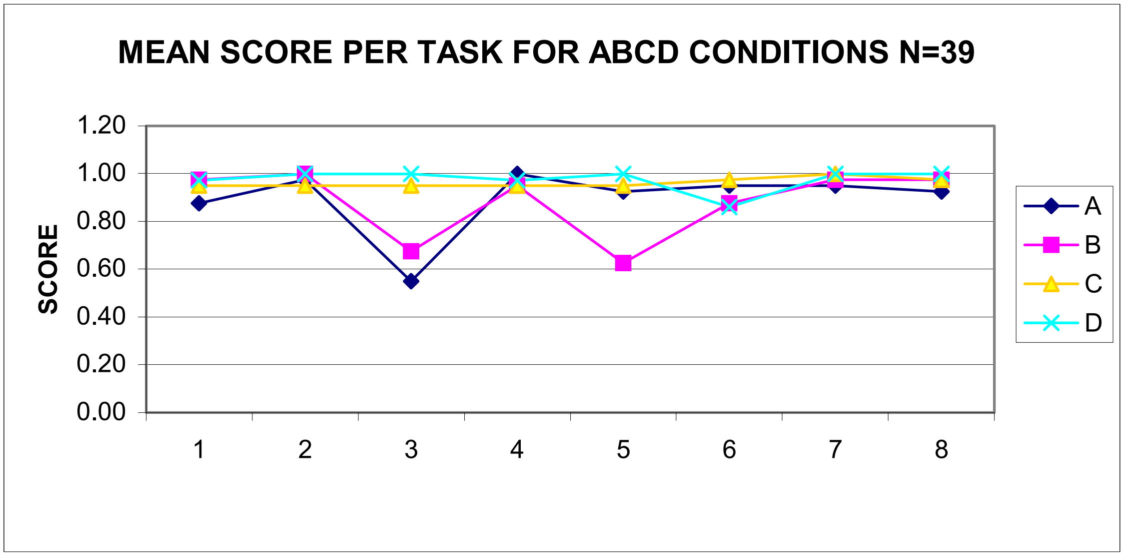


Figure 8.7.2.1a: *Score* per task between conditions A, B, C and D (N = 39) with outlier Case 36 removed

8.7.3 Overall Performance per task between 8 tasks

The *Overall Performance* data-points were calculated in the same manner as those discussed earlier, where the *Time* and *Score* per single task are taken into account, eliminating a trade of factor, i.e. time over accuracy or visa versa.

The *Overall Performance* per task between conditions A, B, C and D shows a similar trend (Figure 8.7.3a) to *Time per task* (Figure 8.7.1a). There is only one case, in task 5 where participants' performance in condition D was not as efficient as in condition C.

The Analysis of Variance of an *Overall Performance* per task between conditions showed a significant difference in tasks 5 ($p > .005$) and 8 ($p > .008$).

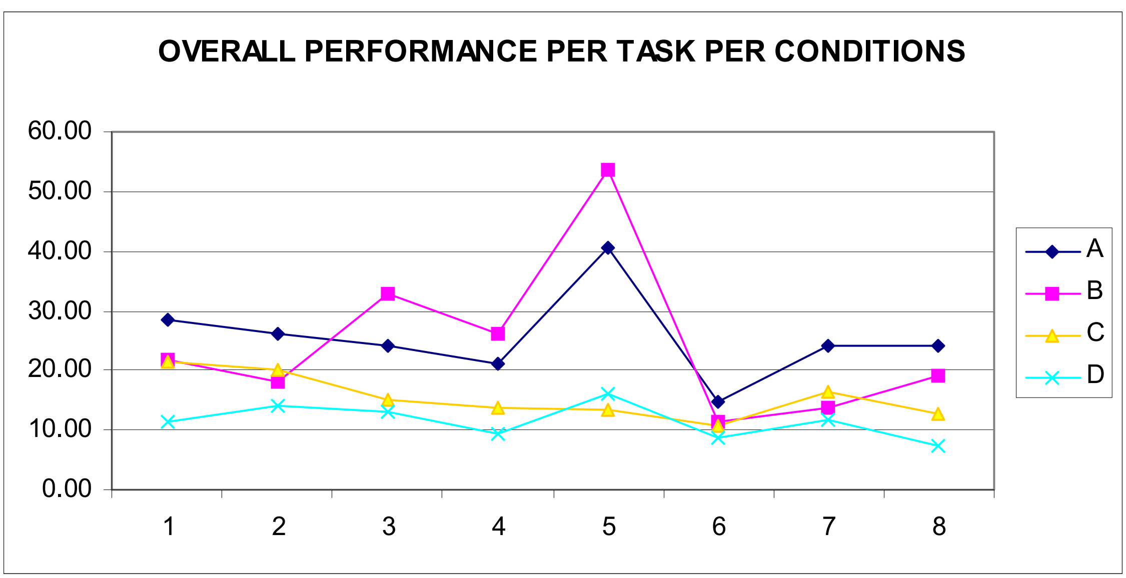


Figure 8.7.3a: *Overall Performance* per task between conditions A, B, C and D

To further understand the difference in participants' performance in individual tasks between the four conditions a data table (Table 8.7.3a) was constructed. The table shows that the trend of Overall Performance is improving with introduction of Mind Reference features onto the display. The table also shows further details of how *Time per task* reduces from task 1 to task 8 in condition A and D. Consequently, it was examined whether there was a significant improvement in pilots performance between these two tasks, first and last.

Descriptives

	Mean *Overall Performance* per condition per task			
Task	**A**	**B**	**C**	**D**
Task 1	28.63	21.76	21.58	11.47
Task 2	26.20	18.10	20.09	14.15
Task 3	24.02	32.77	14.95	13.00
Task 4	21.21	26.24	13.69	9.55
Task 5	40.71	53.70	13.44	16.09
Task 6	14.67	11.49	10.84	8.80
Task 7	24.11	13.75	16.32	11.60
Task 8	24.13	19.01	12.58	7.40
Trend – *Overall Performance* increasing				
Mean	**25.46**	**24.60**	**15.44**	**11.51**
SD	**7.40**	**13.56**	**3.72**	**2.88**

Table 8.7.3a: Mean *Overall Performance* per task in all conditions

From the analysis of mean differences in four different conditions between the first and the last task, the significant difference appeared to be only in the display condition D ($p > .036$).

When means for each task between two conditions (Table 8.7.3b) are compared, A being numerical and D being the maximum application of *Mind Reference* features to the presentation, four things became obvious: (1) condition D always provides better O*verall Performance*; (2) condition D is always at least one and halftimes better, and in three cases two and half times better; (3) *Overall Performance* on condition D improves more on the last task than on the first task. (4) Performance in D condition is most consistent than in A condition throughout all 8 tasks.

Task/ Condition	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**

A	28.6	26.2	24.0	21.2	40.7	14.7	24.1	24.1
D	11.5	14.2	13.0	9.6	16.1	8.8	11.6	7.4
Mean Difference	**2.5**	**1.8**	**1.8**	**2.2**	**2.5**	**1.7**	**2.1**	**3.3**

Table 8.7.3b: Mean difference in *Overall Performance* per task between tasks and A, B, C and D conditions

A Post Hoc analysis of the *Overall Performance* per task showed that there is a significant difference between conditions C and B (p > .012), D and B (p > .020) in task 5, and D and A (p > .008) in task 8.

8.7.3.1 Overall Performance per task without outlier, N = 39

The Overall Performance per individual task between conditions was examined further without an outlier. The Analysis of Variance of *Overall Performance* per task without the outlier (case 36) showed greater, more significant differences, and between more tasks: 2 (p > .043), 3 (p > .054), 5 (p > .002), 6 (p > .048), and 8 (p > .005).

Figure 8.7.3.1a below highlights participants' performance on individual tasks with an outlier (Case 36) removed. The figure shows the pilots O*verall Performance* on individual tasks is always better on display condition D. The table 8.7.3.1a, below, highlights where the significant differences between conditions occurred.

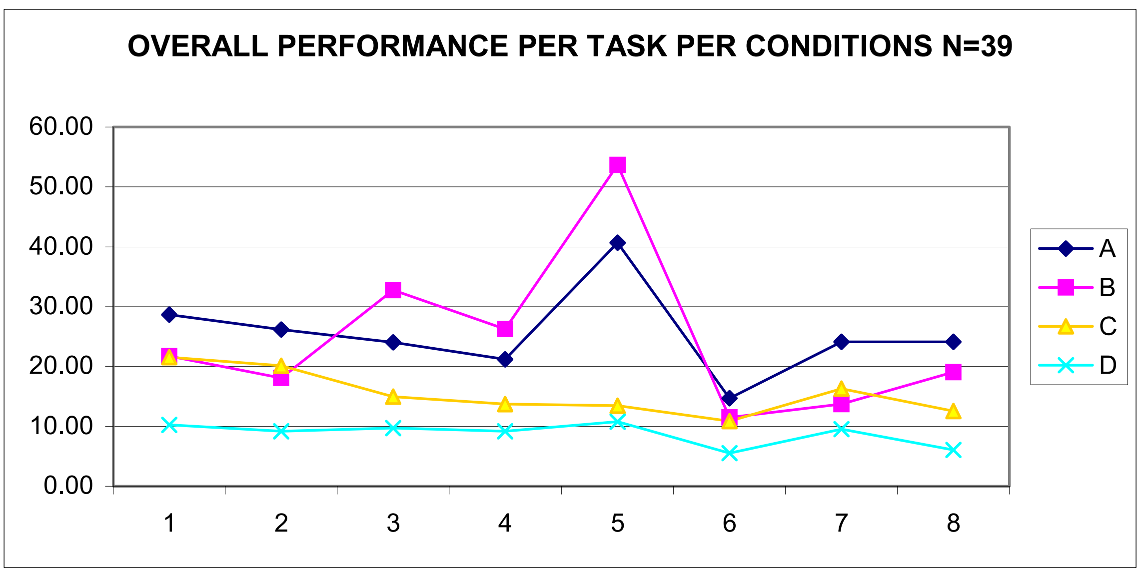


Figure 8.7.3.1a: *Overall Performance* per task between conditions A, B, C and D (N = 39) with outlier Case 36 removed

Task	Display Condition	Significance p < …	Standard Error	Mean Difference
2 task	D and A	.026	5.739	-17.056

3 task	D and B	.054	8.64	-23.033
5 task	C and B	.009	11.832	40.263
	D and B	.006	12.156	42.970
6 task	D and A	.029	3.131	-9.163
8 task	D and A	.004	4.955	-18.116

Table 8.7.3.1a: PostHoc of mean *Overall Performance* per task between tasks and A, B, C and D conditions (N=39) with outlier Case 36 removed

8.8 Discussion for part (i)

8.8.1 Total Time, Total Score and Total Overall Performance

All three types of data collected, *Total Time, Total Score* and *Total Overall Performance* showed the same consistent results, emphasizing there are significant differences between conditions A and D. Participants performed the task of calculating time to altitude more than 200% faster and with significantly fewer errors using the display condition that wholly embodied the *Mind References* concept, in comparison to the numerical presentation. However, this was true only between certain conditions, A and C, A and D and B and D.

There was an apparent ceiling effect in the *Total Score*. The reason for this effect could be because the task itself was relatively easy and all participants were experienced pilots who perform this type of calculating task on a regular basis. Even though the task was relatively easy, there was still a significant improvement in pilots' performance, when *all Mind References* features were present on the display, in comparison to numerical presentation and presentation partially implementing *Mind Reference* features. The numerically represented display features do not match any of the principles of the *Mind Reference* framework – mainly because numbers do not carry the same instantaneous significance unless they are referred against, or associated with, other numerical parameters.

In the process of analysis an outlier was identified and eliminated, as a consequence, the results of participants' performance became even more significant (Table 8.8.1a below). In the case of *Total Overall Performance* between A and D conditions participants performed 300% better on condition D in comparison to the display condition A. The *Total Time* results showed that pilots completed the 8 tasks on condition D more than two and half times faster than those pilots performing the same tasks on display condition A. The *Total Score* results without an outlier showed no further improvement due to the ceiling effect and also because case 36 traded time for accuracy. This made his/her scores high, but increased his/her time spend on each task. By eliminating these results from the data analysis of *Total Score* in fact made the results slightly less significant (Table 8.8.1a).

		Total Time		***Total Score***		***Total Overall Performance***	
		A	D	A	D	A	D

With outlier	**Mean**	03:17.32	01:30.40	7.15	7.80	27.629	11.782
	SD	01:07.92	01:13.39	.738	.405	8.941	9.746
	Sig.	**.004**		**.011**		**.001**	
	Post Hoc Test	A and C; $p < .050$ A and D; $p < .005$		B and D; $p < .032$		A and C; $p < .019$ A and D; $p < .002$ B and D; $p < .021$	
Without outliers	**Mean**	03:17.32	01:10.04	7.15	7.806	27.629	9.169
	SD	01:07.92	00:37.62	.738	.429	8.941	5.481
	Sig.	**.000**		**.014**		**.000**	
	Post Hoc Test	A and C; $p < .022$ A and D; $p < .000$ B and D; $p < .005$		B and D; $p < .041$		A and C; $p < .007$ A and D; $p < .000$ B and D; $p < .002$	

Table 8.8.1a: Comparison between results of *Totals* with and without an outlier

In the *Total Time* data analysis, once the outlier was eliminated, another significant difference between B and D condition transpired (Table 8.8.1a). This was again due to the fact that an outlier, the case 36, traded time for accuracy. Once his data (high *Total Score* and high *Total Time*) was eliminated, the mean *Total Time* in condition D reduced and this increased the mean difference, making the difference between B and D conditions significant, and also increasing the significance between the conditions in *Total Overall Performance*, but the *Total Score* data stayed almost the same.

An interesting finding from the analysis of the *Total Score* is that a significant difference was not seen between conditions A and D, but instead it was between display conditions B and D. Both display conditions A and B had the same level of numerical information presented, but display B had some additional information (i.e., display features) presented using the *Mind Reference* framework to assist the participant in the experimental task. These features were a level-off altitude line and a vertical-speed-triangle. Both features are the result of step-principles 4 (i.e. group complementary information), partially step-principle 3 (i.e. in a meaningful form), step-principle 8 (i.e. represent in a form of reference suitable for the task), and the partial implementation of step-principle 5 (i.e. establish meaningful connections).

From these results it is reasoned that implementing only these step-principles did not assist the participants in performing their tasks with more accuracy when compared with the numerical presentation. However, the participants' performance did improve, although not significantly, on displays B versus A in terms of *Total Time* (by 30 seconds) and *Total Overall performance.*

From the systematic analysis of the results in this first part of the experiment, it becomes clear that the step-principles derived from the *Mind Reference* framework need to be applied in conjunction with one another to improve the participants' performance significantly. The results show that when more step-principles were applied on a condition display, the better participants performed the tasks. From the graphs (*Total Time, Total Score* and *Total Overall Performance*) with and without an outlier there is an evident trend of the participants improving *Total Time* and *Total Overall Performance* from A to B, B to C and C to D. Even through the *Total Score* results had a ceiling effect, where was still a trend of improvement, obvious from B to C and C to D.

When the bare minimum of principles were applied in the design, like in case of condition B, where information is grouped only according to step-principle 4 and the partial application of the 5th step-principle (i.e. dashes are absent), the participant' *Total Time* and *Total Overall Performance* was slightly better, in comparison to condition A. In contrast, in condition C step-principle 2 (i.e. information along a parameter – altitude), 3 (i.e. meaningful parameters – triangle), 5 partially implemented with level-off altitude line being absent (i.e. meaningful connections – dashes), and step-principle 8 (i.e. pilots' reference representation) were combined, and participants' performance improved significantly between A and C. At this stage, in the condition C, significant improvement was seen in pilots *Total Time* and *Total Overall Performance*, even though not all *Mind Reference* step-principles were fully applied. In condition D, all step-principles were integrated in the design of the features to assist the participants in their task, and their performance improved.

8.8.2 Time, Score and Overall Performance per single task

The analysis of data per single task performance showed that participants performed consistently better on condition D in *Time* and *Overall Performance* data. Participants' performed each single task on average at more than double the rate on condition D than on condition A. Once the outlier was eliminated the data showed that participants performed tasks 2.8 times (*Time* data) faster on D than on A conditions. The same was true for the *Overall Performance* data; and without an outlier pilots' *Overall Performance* was 2.9 times better.

The *Time* per single task data analysis showed the same trend as the *Total Time* data once the outlier was eliminated. There was an additional significant mean difference between B and D condition that transpired.

The results on *Time, Score* and *Overall Performance* per single task showed a similar trend of results as the *Total* results (see section 8.8.1) discussed earlier, apart from the *Overall Performance* results per single task, which show only significant mean differences between A and C, A and D conditions with and without an outlier (Table 8.8.2).

		Time		***Score***		***Overall Performance***	
		A	D	A	D	A	D
With outlier	**Mean**	00:24.67	00:11.30	0.89	0.98	25.46	11.51
	SD	00:08.37	00:02.53	0.14	0.04	7.40	2.88
	Sig.	**.004**		**.011**		**.006**	
	Post Hoc Test	A and C; p < .044 A and D; p < .005		B and D; p < .032		A and D; p < .015 B and D; p < .024	
Without outliers	**Mean**	00:24.67	00:08.75	0.89	0.98	25.46	8.76
	SD	00:08.37	00:01.63	0.14	0.05	7.40	1.93
	Sig.	**.000**		**.014**		**.000**	

	Post Hoc Test	A and C; $p < .019$ A and D; $p < .000$ B and D; $p < .007$	B and D; $p < .041$	A and D; $p < .001$ B and D; $p < .002$

Table 8.8.2: Comparison between results of *per single task* with and without an outlier

A further aspect of the data becomes obvious from the analysis of data per single task performance, which is the difference in *Time* performance on the first (task 1) and the last (task 8) tasks across all participants in the four display conditions. The significant ($t = 2.48$; $p < .035$) improvement, however, was only in condition D. There is practically no improvement (less than half a second) between these tasks in condition A, but on the display condition D there was an improvement of 3.5 seconds between first and last task.

The same trend is apparent for the *Overall Performance* per single task. There is a significant difference between the first and the last mean in condition D, but none in any other conditions. The *Score* per single task data does not show any significant differences between the first and the last task means in all of the four conditions. This is again due to the ceiling effect in the *Score* data.

8.8.3 Time, Score and Overall Performance per task between 8 tasks (Table 8.8.3)

At the initial stages of the analysis, with the outlier (case 36) included, the significant differences were observed in a half (4 out of 8 tasks) of the experimental trial tasks, either in some or across all data (*Time, Score* and *Overall Performance*). The significant differences between conditions occurred in tasks with the middle and maximum values of vertical speed, apart from in tasks 1 and 6.

Task 1 was assigned the middle value, but it was also the first task. It is assumed that the difference in participants' performance between conditions did not occur because of the familiarization with the experimental task was still taking place. As was shown and discussed in the previous section there was a difference in participants' performance between the first and the last tasks in all conditions, but the significant difference was only observed in the condition D. Task 6 was also assigned the middle value of vertical speed, but task 2 and 7 (with minimum value) appeared to be arithmetically easier to resolve. Participants' performance in all three tasks did not show any significant difference between conditions.

The significant difference in *Score* data between B and A conditions in task 5, like in no other case, was due to pilots making a more accurate scoring on display A, than on B. It has been pointed out earlier that this is probably due to only a few *Mind Reference* step-principles being implemented on the display that assist in performing an accurate calculation. The rest of the results in the *Score* data, emphasize the advantage of having *Mind Reference* features implemented on the display to assist participants perform tasks quicker and with better accuracy, such as in case of conditions C and D. Task 3, similar to task 5, has a maximum value of vertical speed, and showed that participants perform significantly better in *Score* and *Time* on displays C and D in comparison to display A on this task.

In task 4 participants' *Time* performance showed significant differences between D and A, D and B, but showed no significant difference in the *Score* or *Overall Performance* data. However, if the raw data and graphs are examined there is a clear trend of improvement in participants' performance on this task moving from the A to the D display condition.

The same trends were observed in the *Totals* and *per single task* data did not transpire in all data between tasks. In the analysis of *Total Score* a significant difference was not observed between A and D, but instead it was seen between display conditions B and D. The same trend was observed on task 5, but not on task 3, which appears similar to task 5. Task 3 shows significant mean differences between conditions C and A, D and A.

Participants performed better using *Mind Reference* features when the task was more challenging. They produced significantly better results on condition D, than A on the maximum and middle vertical speed values. Although there was no significant difference in participants' performance in another type of a task (minimum value), the participants *Time* and *Overall Performance* was superior on condition C and D, than on condition A and B.

	Task	**Vertical speed**	***Time***	***Score***	***Overall Performance***
With outlier	**1**	Middle value	-	-	-
	2	Minimum value	-	-	-
	3	*Maximum value*	C and A; $p < .004$ D and A; $p < .003$ D and B; $p < .046$	C and A; $p < .045$ D and A; $p < .020$	-
	4	*Middle value*	D and A; $p < .028$ D and B; $p < .032$	-	-
	5	*Maximum value*	C and A; $p < .011$ D and A; $p < .018$	B and A; $p < .007$ C and B; $p < .003$ D and B; $p < .001$	C and B; $p < .012$ D and B; $p < .020$
	6	Middle value	-	-	-
	7	Minimum value	-	-	-
	8	*Middle value*	D and A; $p < .005$	-	D and A; $p < .008$
Without outlier	**1**	Middle value	-	-	
	2*	*Minimum value*	D and A; $p < .031$	-	D and A; $p < .026$
	3	*Maximum value*	C and A; $p < .002$ C and B; $p < .042$ D and A; $p < .000$ D and B; $p < .008$	C and A; $p < .049$ D and A; $p < .027$	-
	4	*Middle value*	D and A; $p < .028$ D and B; $p < .033$	-	-

	5	*Maximum value*	C and A; $p < .007$ C and B; $p < .046$ D and A; $p < .004$ D and B; $p < .029$	B and A; $p < .006$ C and B; $p < .003$ D and B; $p < .001$	C and B; $p < .009$ D and B; $p < .006$
	6	*Middle value*	-	-	D and A; $p < .029$
	7	Minimum value	-	-	-
	8	*Middle value*	D and A; $p < .002$ D and B; $p < .023$	-	D and A; $p < .004$

** Highlighted expressions are additional significant differences that appeared when the outlier was eliminated.*

Table 8.8.3: Comparison between results of *between 8 tasks* with and without an outlier

It was found when an outlier was eliminated from the data analysis, the participants' there were significant differences in performance between all tasks between conditions except for tasks 1 and 7 that show no significant difference between conditions, although it is still can be observed in the graphs. This could be attributed to the same reasoning discussed earlier, i.e. task 1 being the first task, where pilots are still familiarizing themselves with the display presentation on all conditions; and Task 7 being not challenging enough arithmetically, therefore, not showing any significant difference between conditions.

The analysis without an outlier showed two additional tasks, 2 (minimum value) and 6 (middle value) to have a significant difference in participants' performance between conditions D and A.

Apart from the *Score* data, all *Time* and *Overall Performance* data showed a greater significant difference between the same conditions and additional conditions, such as between conditions C and B in tasks 3 and 5.

Between conditions C and B, where minimal difference was employed in *Mind Reference* features, there was still significant difference observed in tasks 3 and 5. It showed two aspects. (1) When tasks, such as 3 and 5 (maximum value) that are arithmetically difficult compared to other tasks, participants performed better on displays even if not all step-principles were implemented (condition C). (2) When tasks were more arithmetically difficult participants showed a greater difference in performance in favour of displays with *Mind References* principles, where they performed significantly better, i.e., in some cases, discussed earlier, 300% better.

Also, once an outlier was eliminated participants' performance on all tasks became more consistent, steadily improving across all tasks on display condition D in *Time* and *Overall Performance*. On conditions A and B, in some cases participants' performance fluctuated around 300% between tasks.

It is concluded from the above results that participants performed experimental tasks significantly better on the displays employing the *Mind Reference* step-principles.

8.8.4 Post-Questionnaire suggestions from pilots

Despite the fact the most participants said that it was time consuming to count the number of lines in the maximum value presentations of the vertical-speed-triangle, such as in tasks 3 and 5, the participants still performed these tasks significantly faster on the display with the *Mind Reference* symbology (see display condition D), rather than on the numerical representation display (see display condition A).

Participants' general comments were in favour of displays where *Mind References* step-principles were implemented. Even in case 36 (an outlier) said, "*If one can rely on the computer, the triangle + minute marks are very quick + easy. But why not go one step further and display minutes*". It transpired from the discussions after the experiment that pilots (i.e. the participants of the experiments) did not need a precise answer for a task such as the one used in the experiment, but rather in flight they need a quick estimate, which the triangle provided effectively.

The participant pilots also suggested several other situations where similar calculations could be supported. One case is when pilot needs to estimate the amount of fuel left in the tanks and how long (time) and how far (distance and suitable landing) this fuel will last. The second case was about estimating the time and place for starting the descent (i.e., identifying a 3-dimentional point at the top of the descent) in order to later reach a particular navigational point in the air, i.e., the top of final approach.

8.9 Result of Spatial and Arithmetic ability tests

All pilots participated in both parts (I and II) of the experiment completed Spatial and Arithmetic ability tests at the beginning of the session. The objective was to investigate how participants' performance on display conditions was affected by their arithmetic and spatial ability, mainly because the tasks in the two extreme conditions A and D would rely heavily on these abilities. Condition A contained numerical data and required participants to perform an arithmetic task, where condition D had *Mind Reference* features that were represented spatially for this experimental task.

The hypothesis was that participants' performance on the Arithmetic ability test would predict their performance in the display condition A. The correlation and Figure 8.8a and 8.8b show that this is true for both parts of the experiment. These correlations are with ($R = .809$) and without ($R = .703$) outliers in *Total Time* data in the first part of the experiment in between-subject designs, and in the second part of the experiment, in within-subject design study. These results suggest that 65% with and 49% without outliers of variability in *Total Time* performance on display A is predicted by *Total Time* performance on Arithmetic test in the first part of the experiment.

In the first part of the experiment, it was important to eliminate the possibility of these correlations (between *Total Time* on A and *Total Time* on Arithmetic test) to be due to participants' individual difference between groups A and D. The correlation of participants' performance was performed on an Arithmetic test between groups A and D conditions. The results showed that there was no significant correlation between these groups of participants. It is concluded that the correlation between *Total Time* on A and *Total Time* Arithmetic data was not due to individual difference in participants' performance, but due to their measured performance on the Arithmetic test.

In the second part of the experiment (within-subject design), where the data was compared against the same participants performance, similar results were observed in the data with (R = .754, 56% predicted) and without outliers (R = .724, 52% predicted). In addition, it was also observed that the *Total Overall Performance* showed similar results of a significant correlation with (R = .613, 38% predicted) and without outliers (R = .543; 30% predicted). This confirms that individual differences among the participants do not influence the results.

All following correlations figures showed no correlation.

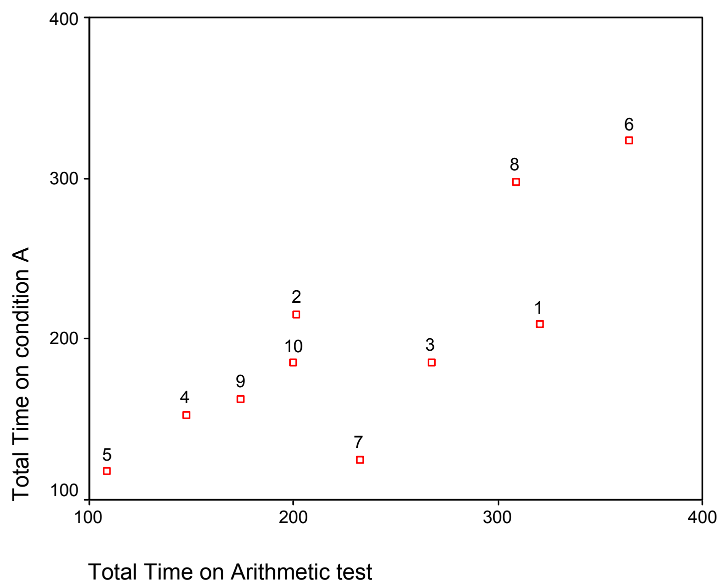


Figure 8.9a: Correlation *Total Time* between condition A and Arithmetic test (part I)

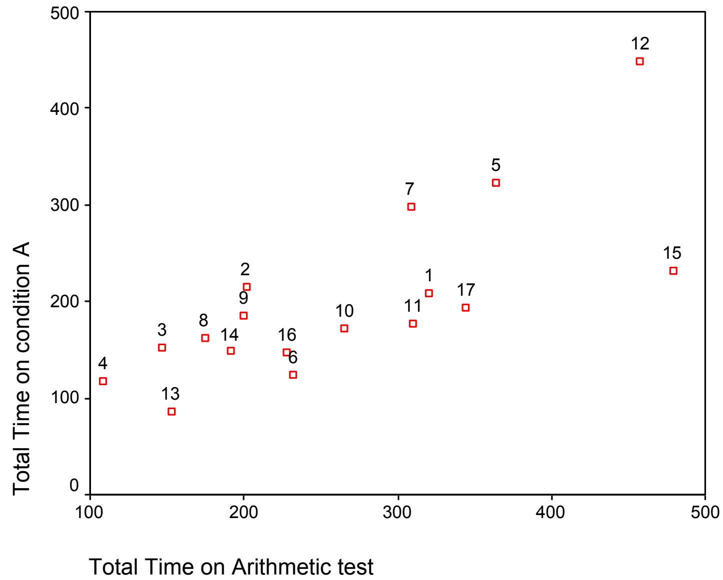


Figure 8.9b: Correlation *Total Time* between condition A and Arithmetic test (part II)

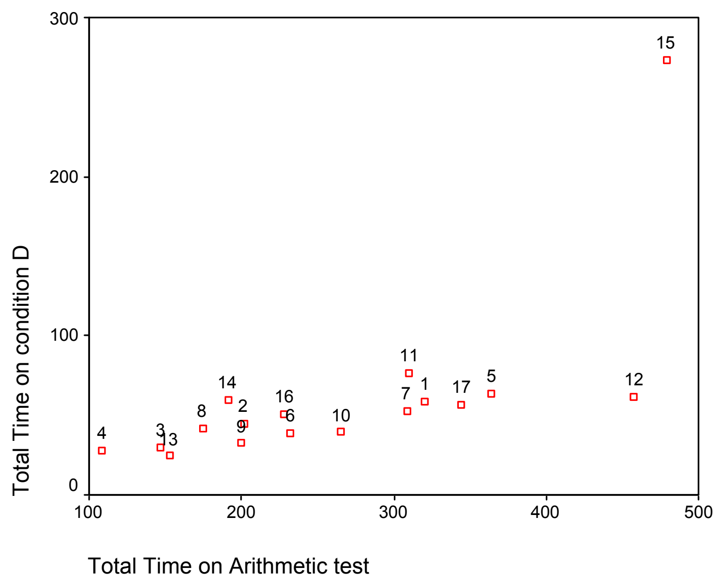


Figure 8.9c: Correlation *Total Score* between condition D and Arithmetic test (part II)

Given the example correlation above, figure 8.9c, this shows both that it is still difficult to fit a regression line to these data-points, and if fitted it would be of a low value, and so a poor predictor. This graph has been included as one the best examples of the correlation (Figure 8.9a and 8.9b). Hence, there appears to be no correlations between participants' performance on arithmetic and spatial ability test versus their performance on display conditions A and D.

Therefore, the second hypothesis that pilots' performance can be predicted by pilots' performance on the Spatial ability test is not supported by these results.

8.10 Method – experiment: part (ii), within-subject, 2 groups, N = 17

Now that the effects of individual *Mind Reference* presentation versus numerical representation in the four different groups of participants (in between-subject design) has been investigated in detail, it is appropriate to explore these effects further in within-subject design experiments. In the second part of the experiment all participants performance is examined on both the two extreme conditions, A (numerical representation) and D (*Mind Reference* presentation) display conditions. This method eliminates any individual differences that could have influenced the result in part I of the experiment. The sample size here was larger, i.e., 17 pilots per condition, and was also counterbalanced, i.e., a random allocation between the two conditions eliminates the order effect.

8.10.1 Participants:

A sample of participants in this part of the experiment comprised 17 pilots, i.e. 17 pilots per display condition. The sample is well balanced across both conditions. One out of 17 pilots was a female. The average age of the pilots who participated was 36 years old (SD = 11.2), ranging from 21 to 61 year old. The flying experience ranged from 80 to 10000 flying hours with an average of 3431 hours and standard deviation of 3055.

8.10.2 Material:

The two prototype displays used and were the same as in the experiment part I display condition A (Figure 8.2.2a - numerical representation) and D (Figure 8.2.2d - *Mind Reference* presentation).

The experimental setup is summarised in the table 8.10.2a below. It is the same as for experimental part I, only there were two display conditions A and D, numerical and *Mind Reference* presentation of information respectively. Two features on the display D, Level-Off-Altitude line and Vertical-Speed-Triangle of 1-minute travel, were assumed to assist in faster completion of the experimental task with less errors, and are both in the display condition D. There were eight calculating tasks per condition that were representative of a variety of possible vertical speed representations, four of which were in a descending representation, and the other four in an ascending representation. Hence, there were 16 data points collected for each participant, eight time-data-points (*Time*) per task and eight error-data-points (*Score*) per task.

Conditions		A **Control Numerical representation**	D ***Mind References* representation**
Features / Tasks		Numbers only	All features present
Ascending	1	Middle value	
	2	Minimum value	
	3	Maximum value	

	4	Middle value
Descending	5	Maximum value
	6	Middle value
	7	Minimum value
	8	Middle value

Table 8.10.2a: Outline of part II experimental tasks setup

The experimental condition A display was a control condition that had none of the *Mind Reference presentation* features. It only contained a basic numerical representation of the information required to estimate the time to a target altitude. The display D had all features together on one display, being represented in numerical and in *Mind Reference* form.

8.10.3 Task and Procedure

The task and procedure was the same as in the experiment part I apart from the additional last four additional steps (8-10). Table 8.10.3a, below, outlines the procedure. These steps were added for pilots to repeat the experimental task on an additional display condition. All participants completed the tasks on both the numerical and the *Mind Reference* displays for comparison in within-subject experimental design.

All participants read and completed a consent form. The form had basic information about the experiment, the participants' rights and a non-discloser agreement. This form also assured that all of the participants had the same information about the experiment.

At the beginning of the experiment all participants were requested to take a spatial test and an arithmetic test. All participants where administered the spatial and arithmetic tests in random order. These tests were the same as in the experiment reported in part I. The tests where introduced to account for the variability in the participants' abilities, which was discussed earlier in this chapter (see section 8.9).

Upon completion of spatial and arithmetic tests participants filled out a questionnaire about their flying experience and then were randomly assigned to either a A or D display condition. They would perform 8 tasks on a randomly allocated first condition. Each participant was asked to calculate time to target altitude as fast and as accurately as they could on each screen, they would write their answer and then go on to the next screen and repeat these steps until they came to a final screen. The software registered time spent on each screen with millisecond accuracy. The participants themselves wrote their answer on an individual score sheet. Upon completion of all the computer tasks, participants completed a questionnaire expressing their opinion on the displays and described how they preformed the tasks. Then the participants were trained on the second display condition, whichever type remained, i.e. if they first did the task on the display condition A, then the second would be the display condition D and visa versa.

Experimental procedure – part II

1. Introduction and consent form
2. Random order pre-test of Spatial and Arithmetic ability
3. Flying experience questionnaire
4. Random allocation of A or D condition display
5. Training on selected condition display
6. Performing 8 tasks on selected condition display
7. Post-questionnaire on the first allocated display
8. Second experimental display condition
9. Training on the second condition display
10. Performing 8 tasks on the second display condition
11. Post-questionnaire on the second display condition

Table 8.10.3a: Experimental procedure – part II

8.11 Results – experiment: part (ii), within-subject, 2 groups, N = 17

The same data-points were collected and analysed in the second part of the experiment (Table 8.11a).

Data-point name	Taken from/Source
Time (Time)	Time taken to complete one task in minutes, seconds, and milliseconds
Score *(Error)*	Full score for correct answer
Overall Performance *(Time over Score)*	Time taken to complete one task divided by the score for the same task
Total Time	Total time taken to complete a complete 8 tasks in minutes, seconds, and milliseconds
Total Score	Sum of scores for 8 tasks (maximum score is 8)
Total Overall Performance *(Total Time over Total Score)*	*'Total Time'* divided by *'Total Score'*

Table 8.11a: Nature of data-points in the experiment

8.12 Analysis of totals over 8 tasks

The analysis began with the *Total* data-points. This gave a general overview of the data in the within-subject design. Then analysis was performed on participants' average task performance, and as with the last analysis, participants' performance between the 8 tasks by comparing the two display conditions A and D was examined.

8.12.1 Total Time (over 8 tasks):

A paired T-test was performed to determine whether there was a difference in pilot performance between condition A and D. The paired T-test result of *Total Time* means between display conditions A and D, showed a significant difference ($p < ..0001$). The figure 8.12.1a and the table (8.12.1a) of means shows that participants completed the same 8 tasks more than 3 times faster on condition D, than they did on condition A. The Standard Deviation of *Total Time* on D condition is less than a minute, compared with the Standard Deviation of 1 minute and 28 seconds. This shows that participants performed the 8 tasks on the display condition D faster and with a more consistent *Total Time*.

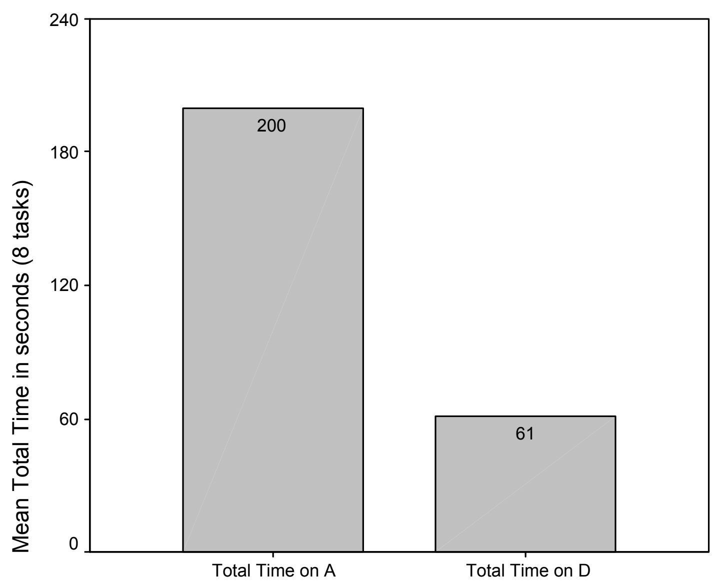


Figure 8.12.1a: Mean of *Total Time* per 8 tasks on A and D display conditions

Paired Samples Statistics

Total Time	Mean	N	Std. Deviation	Std. Error Mean
A	0:03:19.59	17	0:01:28.10	0:00:21.37
D	0:01:00.76	17	0:00:56.70	0:00:13.75

Table 8.12.1a: Mean of *Total Time* per 8 tasks on A and D display conditions

8.12.1.1 Outliers

After inspecting the initial data for extreme values, two outliers were found, one in each condition, case 12 in display condition A and case 15 in display condition D. The outliers were closely examined to determine whether and how these cases affect the results, and whether it was appropriate to continue analysis with these cases being included or excluded.

Case 12 had a maximum score (*Total Score* = 10) on the Arithmetic test, i.e. great accuracy, but the second longest time (*Total Time* = 0:07:37.50, above 85%), where the Mean is 0:04:23.83 with a Standard Deviation of 0:01:46.43 out of the whole group (N=17). It appears in this case the participant chose to sacrifice time over accuracy, when performing the Arithmetic ability test.

Case 15, just like the case 12, had the maximum score (*Total Score* =10) on Arithmetic test, i.e. great accuracy, but the longest time (*Total Time* = 0:07:59.00, above 90%), where Mean of *Total Time* is 0:04:23.83 with Standard Deviation of 0:01:46.43 out of the whole experimental sample (N=17). This participant's *Total Time* is more than two standard deviations away from the mean. This participant also sacrificed time for accuracy.

Cases 12 and 15 had the highest (second and first respectively) time in *Total Time* in Arithmetic test. Both cases 12 and 15 were also listed as the highest (third and second respectively) in *Total Overall Performance* in the Arithmetic test and in the *Total Overall Performance* on Display condition A (Case 12) and D (Case 15) (Figure 8.12.1.1c).

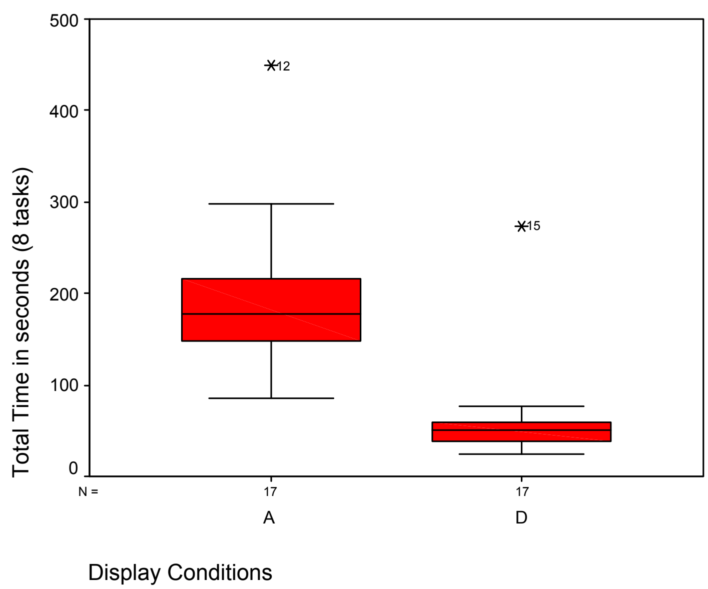


Figure 8.12.1.1a: Outliers in *Total Time* on display conditions A and D

Next, the *Total Score* data was examined for any outliers (Figure 8.12.1.1b). Case 10 was an outlier on display condition A with the *Total Score* of 4, where the group average is 7 (*Total Time* 0:02:51.60, where group mean is 0:03:19.59 with a standard deviation of 0:01:28.10). However, he/she was not an outlier on condition D. On D condition case 10 scored the top score of 8 and faster than the mean *Total Time* 0:00:39.30, where the group mean was 0:01:00.76 with a standard deviation of 0:00:56.70. Case 10 scored below average on the Arithmetic test. Case 10 had a lower than average group performance on the A condition which could be predicted through the Arithmetic test, as it was concluded in section 8.9. It can be concluded that participants performed more efficiently on the D type display, than on the numerical display A. The decision was not to eliminate Case 10 from the analysis.

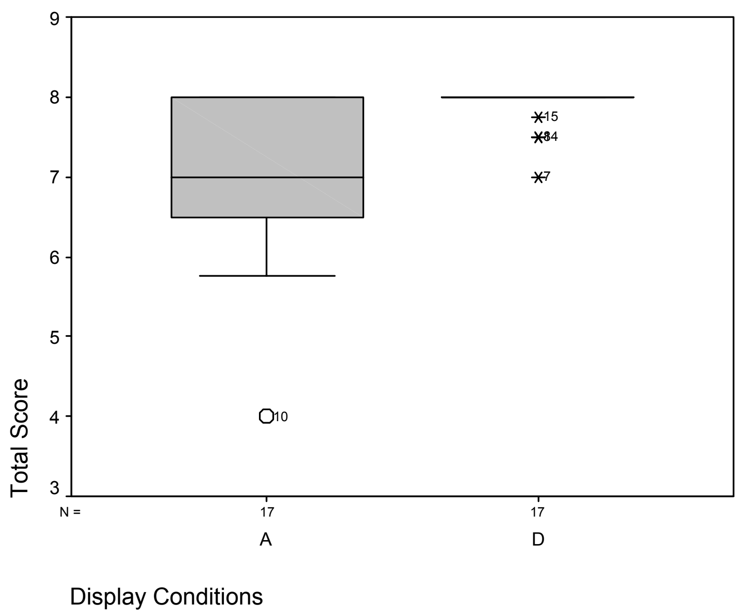


Figure 8.12.1.1b: Outliers in *Total Score* on display conditions A and D

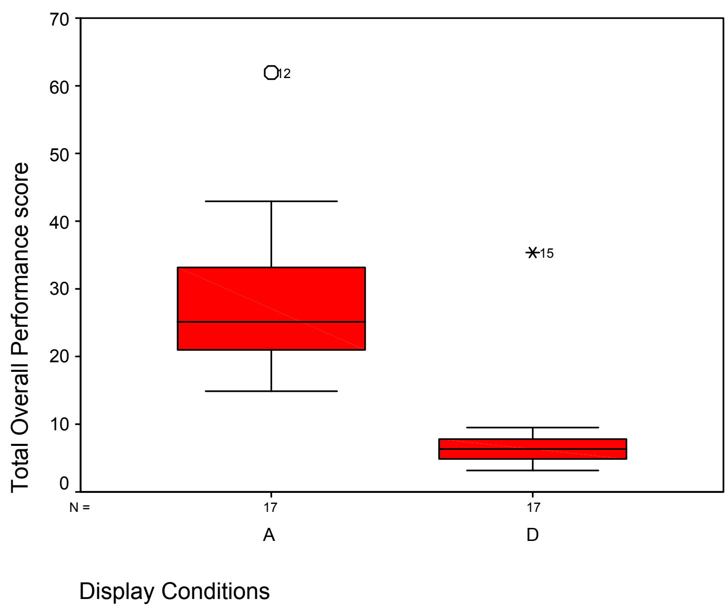


Figure 8.12.1.1c: Outliers in *Total Overall Performance* on display conditions A and D

The decision was to exclude outliers 12 and 15 from the analysis of *Total Score*, *Total Time* and *Total Overall Performance* and to perform the analysis with and without outliers and compare the difference.

8.12.1.2 Total Time without Outliers (over 8 tasks)

Once the outliers were eliminated the difference in participants' performance on experimental displays increased. Participants' performed all 8 tasks 3.8 times faster on D (Figure 8.12.1.2a), than on A with significant difference of $p < ..0001$. The mean table (8.12.1.2a) shows that not only the mean on the display condition D reduced but the Standard Deviation also reduced by only 15 seconds, compared with the Standard deviation on A of 1 minute and 3 seconds, making participants' *Total Time* performance on D even more consistent than when the outliers were included in the analysis.

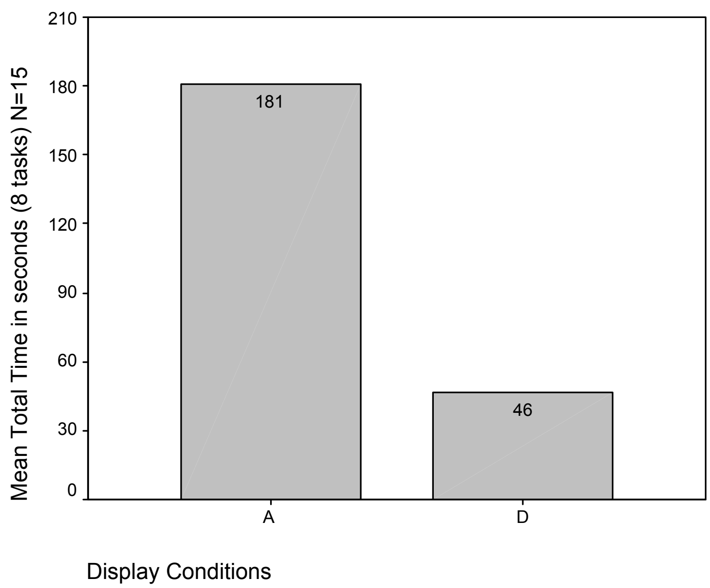


Figure 8.12.1.2a: Mean of *Total Time* per 8 tasks on A and D display conditions with outliers Cases 12 and 15 removed

Paired Samples Statistics

Total Time	Mean	N	Std. Deviation	Std. Error Mean
A	0:03:00.79	15	0:01:03.05	0:00:16.28
D	0:00:46.49	15	0:00:14.86	0:00:03.84

Table 8.12.1.2a: Mean of *Total Time* per 8 tasks on A and D display conditions with outliers Cases 12 and 15 removed

8.12.2 Total Score (over 8 tasks)

Although the difference in the *Total Score* results was not as great as in the *Total Time* data, the difference in means between A and D still showed ($p < .006$) significance. The mean table 8.12.2a shows that despite the mean difference not being great, the difference in standard deviations is large on display condition A. This indicates that participants performed more consistently on display condition D that on A

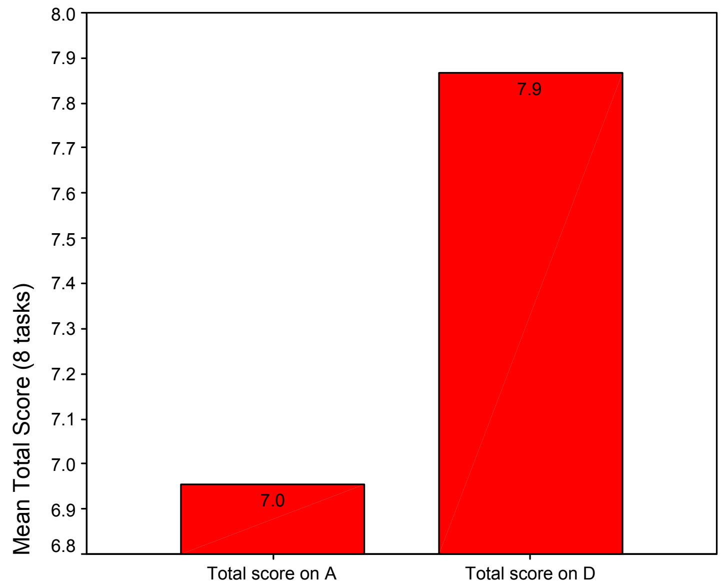


Figure 8.12.2a: Mean of *Total Score* per 8 tasks on A and D display conditions

Paired Samples Statistics

Total Score	Mean	N	Std. Deviation	Std. Error Mean
A	6.9559	17	1.09771	.26623
D	7.8676	17	.28115	.06819

Table 8.12.2a: Mean of *Total Score* per 8 tasks on A and D display conditions

8.12.2.1 Total Score without an Outlier (over 8 tasks)

The elimination of outliers (case 12 and 15) from the analysis did not make any difference to the results.

8.12.3 Total Overall Performance (over 8 tasks)

Despite the *Total Score* data on participants' performance having minimal significant difference between A and D, the *Total Overall Performance*, that takes time into account and shows very significant difference ($p < ..0001$). The figure (8.12.3a) and the two means (table 8.12.3a) below show that the difference between means is more than three and half times.

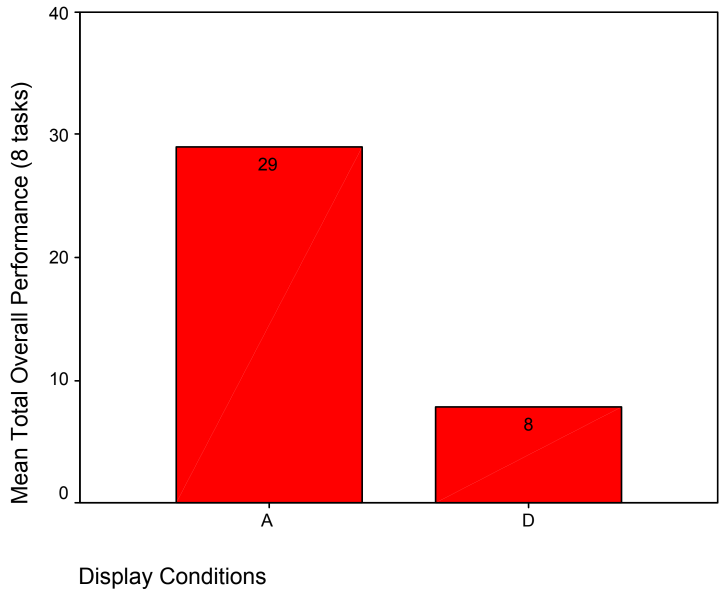


Figure 8.12.3a: Mean of *Total Overall Performance* per 8 tasks on A and D display conditions

Paired Samples Statistics

Total Overall Performance	**Mean**	**N**	**Std. Deviation**	**Std. Error Mean**
A	28.9415	17	12.15743	2.94861
D	7.7653	17	7.33424	1.77881

Table 8.12.3a: Mean of *Total Overall Performance* per 8 tasks on A and D display conditions

8.12.3.1 Total Overall Performance without Outlier (over 8 tasks)

Once the outliers were eliminated the significant difference (p < ..0001) improved and the mean difference (Table 8.12.3.1a) between participants *Total Overall Performance*s raised four and half times with standard deviations to match each condition (Figure 8.12.3.1a). The Standard Deviation in A condition was more than 9 points, where in D condition it was only 2 points, making participants performance on display condition D more consistent, than on A.

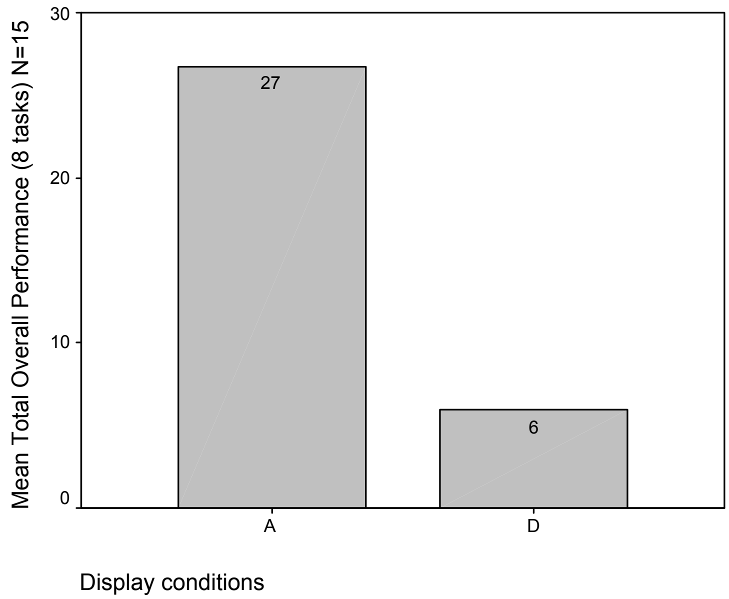


Figure 8.12.3.1a: Mean of *Total Overall Performance* per 8 tasks on A and D display conditions with outliers Cases 12 and 15 removed

Paired Samples Statistics

Total Overall Performance	**Mean**	**N**	**Std. Deviation**	**Std. Error Mean**
A	26.7359	15	9.27541	2.39490
D	5.9307	15	1.92742	.49766

Table 8.12.3.1a: Mean of *Total Overall Performance* per 8 tasks on A and D display conditions with outliers Cases 12 and 15 removed

8.13 Analysis per single task between conditions A and D

8.13.1 Time per single task between conditions A and D

Two-tailed, paired t-tests showed that there was a significant difference in *Time* ($p < 0.001$) per single tasks (i.e., total of 8 tasks) between display conditions A and D (Figure 8.13.1a). The difference in participants average *Time* performance per single task on condition D was more than 3 times faster than on condition A (Table 8.13.1a). At times participants performed a single task on D condition 4 times faster, than on A.

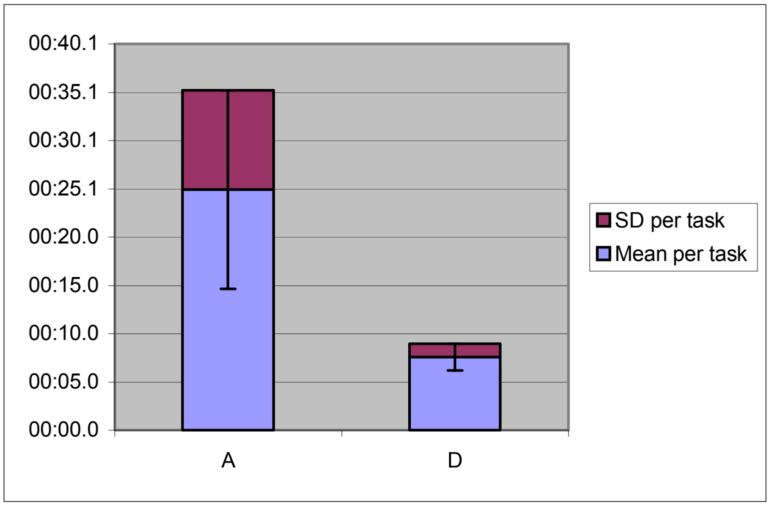


Figure 8.13.1a: Mean of *Time* per single task on A and D display conditions

	A	D
Mean per single task	**00:25.0**	**00:07.6**
SD per single task	00:10.3	00:01.4

Table 8.13.1a: Mean of *Time* per task on A and D display conditions

8.13.1.1 Time per single task between conditions A and D without outliers

A further Two-tailed, paired t-test showed that there was a significant difference between *Time* ($p < 0.001$) in the single tasks in display conditions A and D without outliers. From the table (8.13.1.1a) and in figure (8.13.1.1a) below it is evident that participants' *Time* performance on a single task was much superior on D than on A. On average the participants reduced their *Time* spent on a single task by 4 times.

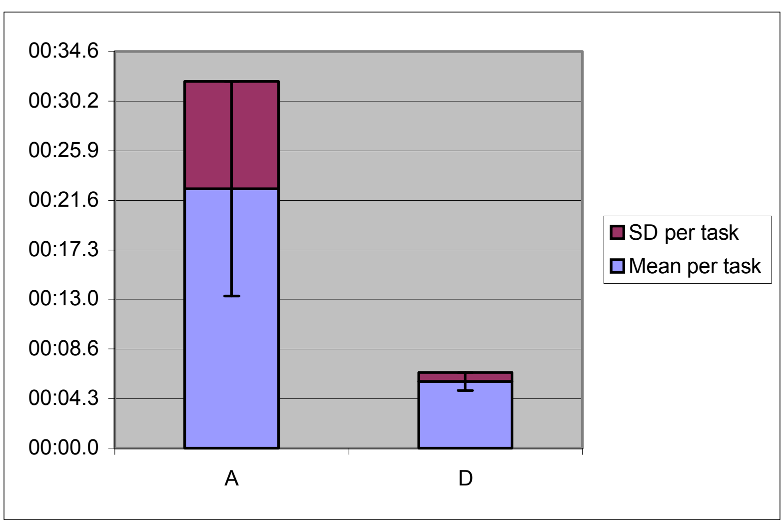


Figure 8.13.1.1a: Mean of *Time* per single task on A and D display conditions with outliers Cases 12 and 15 removed, N=15

	A	D
Mean per single task	**00:22.6**	**00:05.8**
SD per single task	00:09.4	00:00.8

Table 8.13.1.1a: Mean of *Time* per task on A and D display conditions without outliers N=15

8.13.2 Score per single task between conditions A and D

A two-tailed, paired t-test showed that there was no significant difference between the *Score* on single tasks in the display conditions A and D. Although the participants' *Score* performance did not appear to be significantly different between A and D conditions, the table (8.13.2a) and the figure (8.13.2a) below highlight the difference in participants' performance.

There are two reasons that there is no statistically significant difference between *Score* per single task data in pilots' performance. One, there is a ceiling effect, similar to the effect in part I of this experiment, discussed in section 8.7.2. Two, the larger sample might have shown the significant difference.

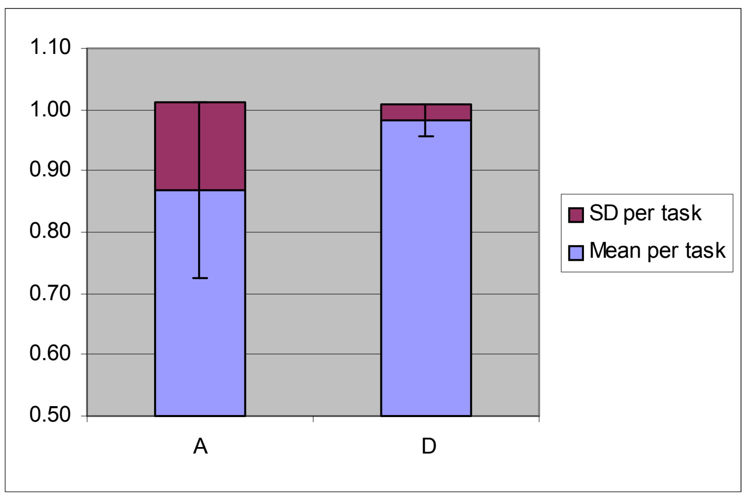


Figure 8.13.2a: Mean of *Score* per single task on A and D display conditions

	A	D
Mean per single task	**0.87**	**0.98**
SD per single task	0.14	0.03

Table 8.13.2a: Mean of *Score* per task on A and D display conditions

8.13.2.1 Score per single task between conditions A and D without an outlier

The same trends in *Score* per single task were observed in the analysis without outliers as with the outliers.

8.13.3 Overall Performance per single task between conditions A and D

Despite the fact the *Score* per single task data did not show a statistically significant difference between the two display conditions, the *Overall Performance* of participants per single task data did show significant difference. The Two-tailed, paired t-test showed that there was a significant difference between *Overall Performance* ($p < 0.001$) on single tasks between display conditions A and D. The mean difference between conditions A and D was more than 3 times. Mean table (8.13.3a) and figure (8.13.3a) show the difference in pilots *Overall Performance* per single task in both conditions.

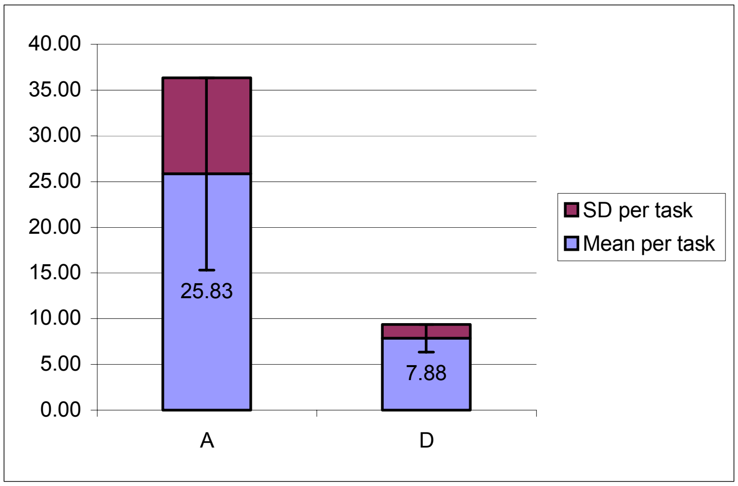


Figure 8.13.3a: Mean of *Overall Performance* per single task on A and D display conditions

	A	D
Mean per single task	**25.83**	**7.88**
SD	10.51	1.51

Table 8.13.3a: Mean of *Overall Performance* per task on A and D display conditions

8.13.3.1 Overall Performance per single task between conditions A and D without outliers

Once outliers were eliminated the difference in pilots' *Overall Performance* per single task increased to three and half times between conditions A and D (table 8.13.3.1a and figure 8.13.3.1a). The Two-tailed, paired t-test showed that there was a significant difference between *Overall Performance* ($p < 0.002$) single tasks in display conditions A and D without outliers.

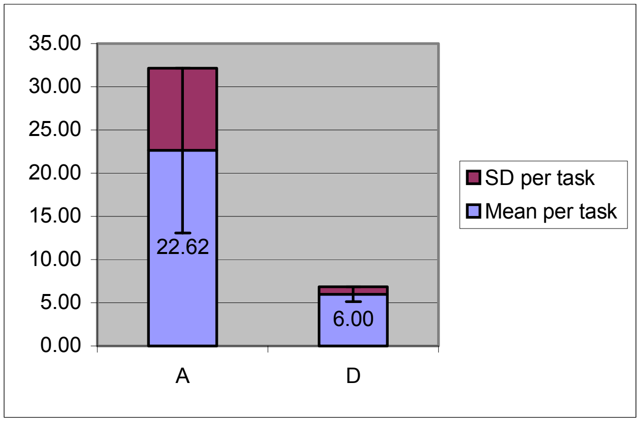


Figure 8.13.3.1a: Mean of *Overall Performance* per single task on A and D display conditions with outliers Cases 12 and 15 removed, N=15

	A	D
Mean per single task	**22.62**	**6.00**
SD	9.53	0.88

Table 8.13.3.1a: Mean of *Overall Performance* per task on A and D display conditions with outliers Cases 12 and 15 removed, N=15

8.14 Analysis per task between 8 tasks

The last stage of the analysis looked at participants' performance on 8 individual tasks and compared these between the two conditions.

8.14.1 Time per task between 8 tasks:

Participants' *Time* performance on 8 tasks showed significant difference in all tasks between display conditions A and D, apart from task 6 (Table 8.14.1a). As was discussed in the first part of the experiment, the reason for this is no significant difference could be attributed to task 6 as it was relatively easy to complete arithmetically. This means that participants completed this task on average quite fast (11.14 seconds) on display condition A, even though the same task was still completed faster in condition D (7.86 seconds) (Table 8.14.1b and Figure 8.14.1a).

Paired Samples Test

***Time* per task between A and D**	**Paired Differences**					**t**	**df**	**Sig. (2-tailed)**
	Mean	**Std. Deviation**	**Std. Error Mean**	**95% Confidence Interval of the Difference**				
				Lower	Upper			
Task 1	0:00:14.47	0:00:11.10	0:00:02.69	0:00:08.76	0:00:20.18	5.373	16	**.000**
Task 2	0:00:15.64	0:00:15.06	0:00:03.65	0:00:07.90	0:00:23.39	4.281	16	**.001**
Task 3	0:00:30.19	0:00:21.84	0:00:05.30	0:00:18.96	0:00:41.42	5.700	16	**.000**
Task 4	0:00:13.49	0:00:12.03	0:00:02.92	0:00:07.30	0:00:19.67	4.622	16	**.000**

Task 5	0:00:32.28	0:00:19.52	0:00:04.73	0:00:22.24	0:00:42.31	6.819	16	**.000**
Task 6	0:00:03.27	0:00:09.62	0:00:02.33	-0:00:01.68	0:00:08.22	1.402	16	.180
Task 7	0:00:12.02	0:00:16.08	0:00:03.90	0:00:03.75	0:00:20.28	3.082	16	**.007**
Task 8	0:00:17.50	0:00:16.58	0:00:04.02	0:00:08.97	0:00:26.03	4.352	16	**.000**

Table 8.14.1a: T-test *Time* per task between tasks and A and D display conditions

The data in the table 8.14.1b and figure 8.14.1a below show that participants performed all tasks on display condition D faster and, comparatively, at more a constant average *Time* per task than they were able to on display condition A.

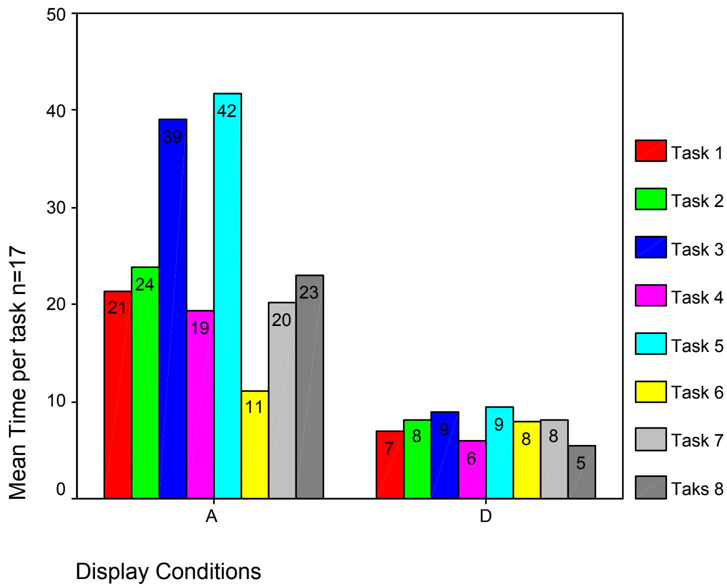


Figure 8.14.1a: Mean of *Time* per task on A and D display conditions

Paired Samples Statistics

	Mean *Time* per task	
Task	**A**	**D**
1	0:00:21.38	0:00:06.91
2	0:00:23.79	0:00:08.15
3	0:00:39.05	0:00:08.86
4	0:00:19.38	0:00:05.89
5	0:00:41.71	0:00:09.44
6	0:00:11.14	0:00:07.86
7	0:00:20.19	0:00:08.18
8	0:00:22.96	0:00:05.46

Table 8.14.1b: Mean of *Time* per task on A and D display conditions

8.14.1.1 Time per task between 8 tasks without outliers, N = 15

Once the two outliers, cases 12 and 15, were eliminated from the analysis, the significant difference was across all tasks between the two conditions (Table 8.14.1.1a). Participants performed significantly faster on condition D, and on task 5 performed more than 5 times faster (Table 8.14.1.1b). Again, participants were recorded a steady *Time* performance throughout all tasks on display condition D (Figure 8.14.1.1a).

Paired Samples Test

Time per task on A and D	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
Task 1	0:00:14.65	0:00:10.59	0:00:02.74	0:00:08.79	0:00:20.52	5.357	14	**.000**
Task 2	0:00:17.72	0:00:09.63	0:00:02.49	0:00:12.39	0:00:23.05	7.128	14	**.000**
Task 3	0:00:27.79	0:00:16.75	0:00:04.33	0:00:18.51	0:00:37.06	6.424	14	**.000**
Task 4	0:00:12.29	0:00:08.06	0:00:02.08	0:00:07.83	0:00:16.76	5.909	14	**.000**
Task 5	0:00:32.00	0:00:20.04	0:00:05.18	0:00:20.90	0:00:43.10	6.183	14	**.000**
Task 6	0:00:04.82	0:00:03.54	0:00:00.91	0:00:02.86	0:00:06.78	5.273	14	**.000**
Task 7	0:00:10.04	0:00:08.73	0:00:02.25	0:00:05.21	0:00:14.87	4.456	14	**.001**
Task 8	0:00:15.01	0:00:09.86	0:00:02.55	0:00:09.55	0:00:20.47	5.893	14	**.000**

Table 8.14.1.1a: T-test *Time* per task between tasks and A and D display conditions with outliers Cases 12 and 15 removed, N=15

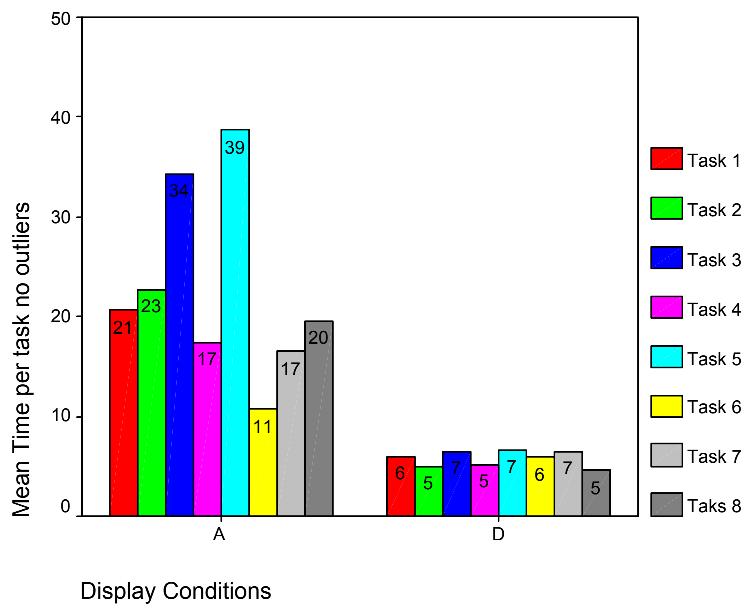


Figure 8.14.1.1a: Mean of *Time* per task on A and D display conditions with outliers Cases 12 and 15 removed, N=15

	Mean *Time* per task	
Task	**A**	**D**
1	0:00:20.69	0:00:06.03
2	0:00:22.72	0:00:05.00
3	0:00:34.32	0:00:06.53
4	0:00:17.46	0:00:05.17
5	0:00:38.69	0:00:06.69
6	0:00:10.75	0:00:05.93
7	0:00:16.55	0:00:06.51
8	0:00:19.60	0:00:04.59

Table 8.14.1.1b: Mean of *Time* per task on A and D display conditions with outliers Cases 12 and 15 removed, N=15

8.14.2 Score per task between 8 tasks

The *Score* per individual task performance showed a difference between A and D conditions only in two tasks 3 and 5. Tasks 3 and 5 were relatively difficult arithmetically, as discussed in the part one of the experiment. However, the figure (8.14.2a) below shows that participants performed consistently better on display condition D, than on A. Participants managed to make no errors in task 4 on D condition, where the same participants, on average, made mistakes on all 8 tasks on display condition A (Table 8.14.2b). All 17 participants made no errors in tasks 2, 3, 7 and 8 on condition D. On Condition A, however, there were no such cases.

Paired Samples Test

***Score* per task on A and D**	**Paired Differences**					**t**	**df**	**Sig. (2-tailed)**
	Mean	**Std. Deviation**	**Std. Error Mean**	**95% Confidence Interval of the Difference**				
				Lower	Upper			
Task 1	.0294	.23188	.05624	-.0898	.1486	.523	16	.608
Task 2	-.1029	.26603	.06452	-.2397	.0338	-1.595	16	.130
Task 3	-.4559	.48602	.11788	-.7058	-.2060	-3.867	16	**.001**
Task 4	.0000	.17678	.04287	-.0909	.0909	.000	16	1.000
Task 5	-.1912	.31287	.07588	-.3520	-.0303	-2.519	16	**.023**
Task 6	-.0147	.13893	.03370	-.0861	.0567	-.436	16	.668
Task 7	-.0882	.26430	.06410	-.2241	.0477	-1.376	16	.188
Task 8	-.0882	.17547	.04256	-.1785	.0020	-2.073	16	.055

Table 8.14.2a: T-test *Score* per task on A and D display conditions

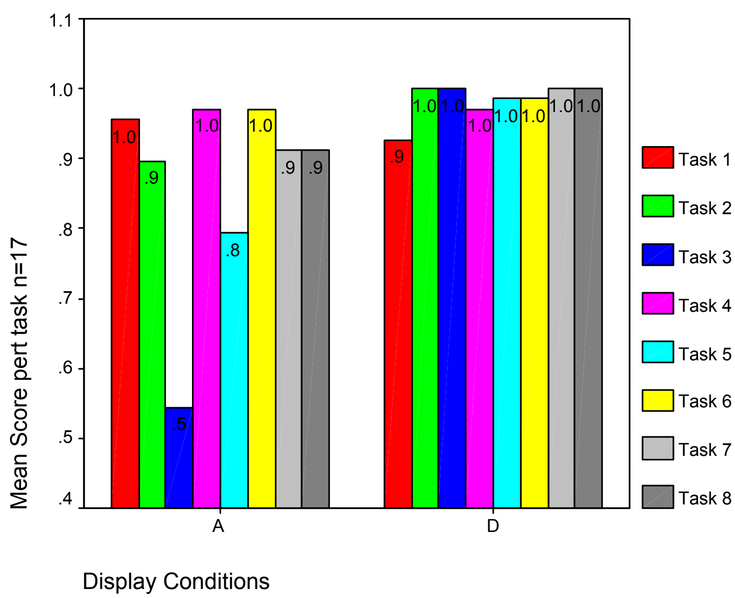


Figure 8.14.2a: Mean of *Score* per task on A and D display conditions

	Mean *Score* per task	
Task	**A**	**D**
1	.9559	.9265
2	.8971	**1.0000**

3	.5441	**1.0000**
4	.9706	.9706
5	.7941	.9853
6	.9706	.9853
7	.9118	**1.0000**
8	.9118	**1.0000**

Table 8.14.2b: Mean of *Score* per task on A and D display conditions

8.14.2.1 Score per task between 8 tasks without an outlier, N = 16

The same trends in *Score* per task in 8 tasks without outliers were observed in the analysis with the outliers accounted for.

8.14.3 Overall Performance per task between 8 tasks

The *Overall Performance* per task in 8 tasks between conditions A and D, showed there was significant difference in participants' performance in all tasks, apart from two, tasks 3 and 6 (Table 8.14.3a). Task 6 was mentioned earlier as arithmetically easy for participants to complete in both conditions, but still participants performed better on display condition D (Figure 8.14.3a and Table 8.14.3b). As discussed in the outliers section of this part of the experiment, case 15 had traded the time spend on each task for accuracy and had double-checked each answer using both methods. This made his/her *Time* data high, which in turn increased his/her *Overall Performance* score on display condition D. This is the reason for difference in mean score on task 3 being not being recorded as significant.

Paired Samples Test

***Overall Performance* per task on A and D**	**Paired Differences**					**t**	**df**	**Sig. (2-tailed)**
	Mean	**Std. Deviation**	**Std. Error Mean**	**95% Confidence Interval of the Difference**				
				Lower	Upper			
Task 1	16.4294	18.05530	4.37905	7.1462	25.7126	3.752	16	**.002**
Task 2	14.9176	15.47850	3.75409	6.9593	22.8760	3.974	16	**.001**
Task 3	23.1863	46.65826	11.31629	-.8032	47.1757	2.049	16	.057
Task 4	14.0588	12.07120	2.92770	7.8524	20.2653	4.802	16	**.000**
Task 5	37.5333	22.42772	5.43952	26.0021	49.0646	6.900	16	**.000**
Task 6	4.2843	11.38760	2.76190	-1.5707	10.1393	1.551	16	.140
Task 7	13.0471	19.03763	4.61730	3.2588	22.8353	2.826	16	**.012**
Task 8	20.1980	17.17213	4.16485	11.3689	29.0271	4.850	16	**.000**

Table 8.14.3a: T-Test – *Overall Performance* per task on A and D display conditions

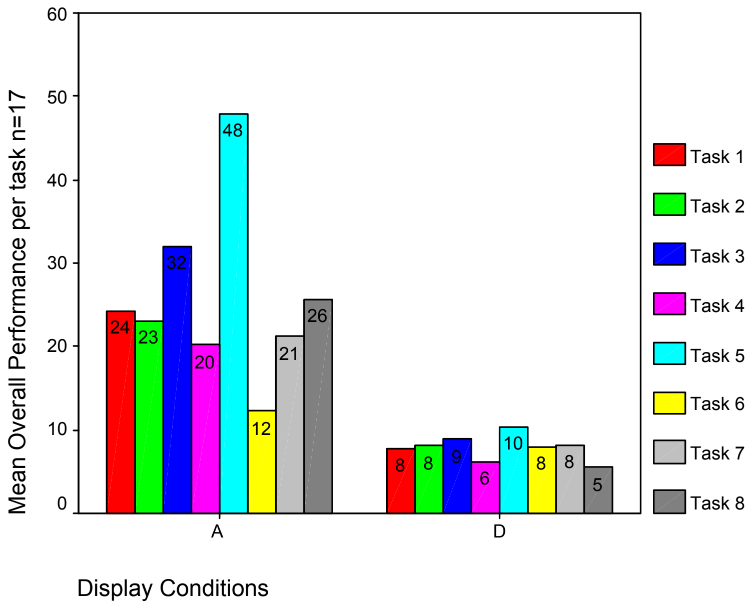


Figure 8.14.3a: Mean of *Overall Performance* per task on A and D display conditions

	Mean *Overall Performance* per task	
Task	**A**	**D**
1	24.2549	7.8255
2	23.0647	8.1471
3	32.0451	8.8588
4	20.2588	6.2000
5	47.9137	10.3804
6	12.2529	7.9686
7	21.2235	8.1765
8	25.6627	5.4647

Table 8.14.3b: Mean of *Overall Performance* per task on A and D display conditions

8.14.3.1 Overall Performance per task between 8 tasks without outliers, N = 15

When the outliers were eliminated in both display conditions, it was observed that all 8 tasks showed a significant difference in participants *Overall Performance* per individual task between the two conditions (Table 8.14.3.1a). From the figure (8.14.3.1a) and table (8.14.3.1b) below it can also be seen that participants' performance became even more consistent across all eight tasks.

Paired Samples Test

***Overall Performance* per task on A and D**	**Paired Differences**					**t**	**df**	**Sig. (2-tailed)**
	Mean	**Std. Deviation**	**Std. Error Mean**	**95% Confidence Interval of the Difference**				
				Lower	Upper			
Task 1	16.8733	18.50320	4.77751	6.6266	27.1201	3.532	14	**.003**
Task 2	16.9000	10.52297	2.71702	11.0726	22.7274	6.220	14	**.000**
Task 3	13.3911	23.11196	5.96748	.5921	26.1901	2.244	14	**.042**
Task 4	12.9400	8.22321	2.12322	8.3861	17.4939	6.095	14	**.000**

Task 5	37.6667	20.37971	5.26202	26.3808	48.9526	7.158	14	**.000**
Task 6	5.9689	7.14131	1.84388	2.0142	9.9236	3.237	14	**.006**
Task 7	11.2067	14.13357	3.64927	3.3798	19.0336	3.071	14	**.008**
Task 8	18.0644	11.62880	3.00254	11.6246	24.5043	6.016	14	**.000**

Table 8.14.3.1a: T-Test - *Overall Performance* per task on A and D display conditions without outliers cases 12 and 15

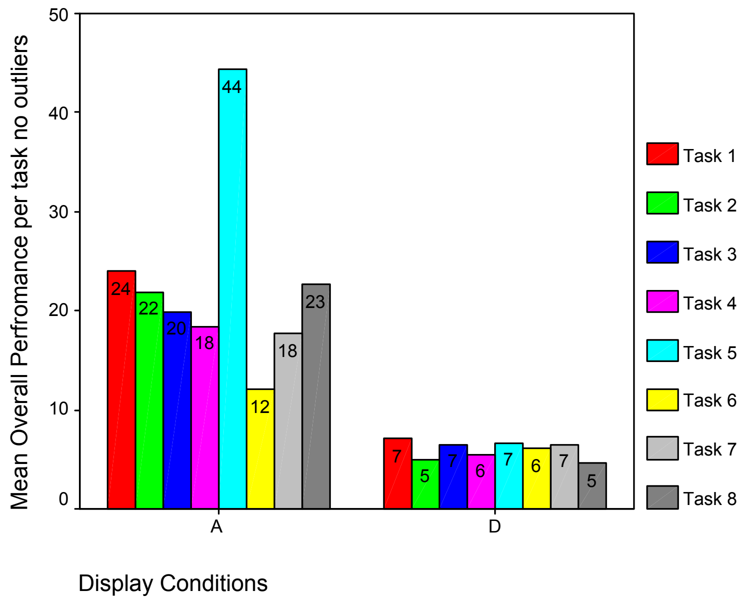


Figure 8.14.3.1a: Mean of *Overall Performance* per task on A and D display conditions with outliers Cases 12 and 15 removed, N=15

	Mean *Overall Performance* per task	
Task	**A**	**D**
1	23.9489	7.0756
2	21.9000	5.0000
3	19.9244	6.5333
4	18.4600	5.5200
5	44.3600	6.6933
6	12.0200	6.0511
7	17.7200	6.5133
8	22.6578	4.5933

Table 8.14.3.1b: Mean of *Overall Performance* per task on A and D display conditions with outliers Cases 12 and 15 removed, N=15

8.15 Discussion for part (ii)

There was no variability in participants' abilities between groups in this part of the experiment as this was designed as a within-subject experiment. All 17 participants performed the experimental task on both display conditions. All data on participants' performance on the display conditions A and D was not influenced by participants individual differences, such as was the case in the part I of this experiment.

8.15.1 Total Time, Total Score and Total Overall Performance

Total Time, Total Score and *Total Overall Performance* showed the same consistent results, emphasising the difference between conditions A and D. Participants' performance on all 8 experimental tasks on the display condition D with *Mind Reference* features was more than three times faster and with significantly less error than on the condition A (numerical representation) display. The *Total Overall Performance* shows that participants performances improved more than three and half times on display condition D (Table 8.15.1a).

It was found again, once the outliers were eliminated, the data showed even further significant difference between participants' performance on display condition A and D. Participants' performance in *Total Time* improved, being 3.8 times faster on the display where *Mind Reference* principles were used in the design of its features. The *Total Overall Performance* improved by four and half times. The *Total Score* results had the ceiling effect, just like in the first part of the experiment. The *Total Score* results though showed no further improvement, when outliers were eliminated.

		Total Time		***Total Score***		***Total Overall Performance***	
		A	D	A	D	A	D
With outlier	**Mean**	03:19.59	01:00.76	6.956	7.868	28.942	7.765
	SD	01:28.10	00:56.70	1.1	.281	12.157	7.334
	Sig.	**.000**		**.006**		**.000**	
Without outliers	**Mean**	03:00.79	00:46.49	7.14	7.86	26.736	5.931
	SD	01:03.05	00:14.86	.816	.288	9.275	1.927
	Sig.	**.000**		**.007**		**.000**	

Table 8.15.1a: Comparison between results of *Totals* with and without an outlier

8.15.2 Time, Score and Overall Performance per single task

Data on participants' performance per single task showed the same trends (Table 8.15.2a) as the *Totals* data (Table 8.15.1a). Condition D offered participants display features that give them an advantage in performance on the experimental task, when compared with display condition A.

		Total Time		***Total Score***		***Total Overall Performance***	
		A	**D**	**A**	**D**	**A**	**D**
With outlier	**Mean**	00:25.0	00:07.6	0.87	0.98	25.83	7.88
	SD	00:10.3	00:01.4	0.14	0.03	10.51	1.51
	Advantage over A	3.3 times faster		Better		3.3 times better	
Without outliers	**Mean**	00:22.6	00:05.8	0.89	0.98	22.62	6.00
	SD	00:09.4	00:00.8	0.14	0.03	9.53	0.88

	Advantage over A	3.9 times faster	No further	3.8 times better

Table 8.15.2a: Comparison between results of *per single task* with and without outliers

8.15.3 Time, Score and Overall Performance per task between 8 tasks

When comparing each of the 8 tasks between the two conditions, participants *Time* and *Overall Performance* was always better on display condition D. The same is true for *Score* data, apart for one occasion when on average participants scored better by 0.03 point on task 1 on display A, however in *Time* and *Overall Performance* on task 1 participants showed a significant advantage performing the task on display D, than A.

The upper half of the table (8.15.3a) below shows significant differences in the participants' performance with all participants data included, and the bottom half shows participants' significant performance without outliers.

In the upper half of the table, the *Time* per task data shows a significant difference on all tasks apart from task 6. As discussed previously, task 6 was relatively easy to perform and the results did not show a significant difference between the two conditions. However, from mean data (11.14 seconds on A; 07.86 seconds on D), it was evident that participants found this arithmetic task 6 relatively easy, but still performed better on display condition D.

The *Score* data per task had a ceiling effect as discussed in the discussion part of the previous sections. As a result the *Score* data showed only significant difference in tasks that were relatively difficult to perform arithmetically on display A, where participants made more errors. However, the same participants performed tasks, 3 and 5, with significantly fewer errors on display condition D.

The *Overall Performance* data per task indicates significant differences in participants' performance on 6 out of the 8 consecutive tasks. The mean data (Figure 8.14.3a above in the *Overall Performance* per task section) shows that participants consistently performed tasks better on the display with *Mind References* features.

	Task	Vertical speed	*Time*	*Score*	*Overall Performance*
With outlier	**1**	Middle value	**$p < .000$**	-	**$p < .002$**
	2	Minimum value	**$p < .001$**	-	**$p < .001$**
	3	*Maximum value*	**$p < .000$**	**$p < .001$**	-
	4	*Middle value*	**$p < .000$**	-	**$p < .000$**
	5	*Maximum value*	**$p < .000$**	**$p < .023$**	**$p < .000$**
	6	Middle value	-	-	-

	7	Minimum value	**p < .007**	-	**p < .012**
	8	*Middle value*	**p < .000**	-	**p < .000**
Without outlier	1	Middle value	**p < .000**	-	**p < .003**
	2	*Minimum value*	**p < .000**	-	**p < .000**
	3	*Maximum value*	**p < .000**	**.003**	**p < .042**
	4	*Middle value*	**p < .000**	-	**p < .000**
	5	*Maximum value*	**p < .000**	**.044**	**p < .000**
	6	*Middle value*	**p < .000**	-	**p < .006**
	7	Minimum value	**p < .001**	-	**p < .008**
	8	*Middle value*	**p < .000**	-	**p < .000**

Table 8.15.3a: Comparison between results of *between 8 tasks* with and without an outlier

The second bottom half of the table shows the significant differences in means between the two conditions without the outliers. The *Score* data per task showed the significant difference only in the two tasks 3 and 5, similar to the data where all pilots were included in the analysis. Participants, however, showed significantly better performance on the display condition D at all times in all 8 consecutive tasks in *Time* and *Overall Performance* data.

8.15.4 Post-Questionnaire suggestions from participants

When asked about the preference of the vertical speed representation, all 17 participants found it faster and easier to use the *Mind Reference* presentation to the numerical presentation.

8.16 Conclusion

The results from evaluating the display features designed using *Mind Reference* framework principles have shown a significant improvement in pilots' (i.e. the participants of the experiment) performance on one particular calculating task, that of calculating time to altitude. From this it is considered that this framework may also be usable for the design of display of features that support similar calculating and estimating tasks, such as fuel consumption over time and distance, or time and distance left to next navigation point.

The results point to the opportunity of generating representations through the use of the *Mind Reference* framework for vital information that needs instant calculations and estimations. These representations will minimize pilots' cognitive effort spent on repetitive, but essential tasks while flying, and also minimize errors and time taken by the pilot to complete these calculations.

Moreover, the use of this framework can be extended to other focal types of pilots' tasks, such as problem solving, monitoring and managing tasks, as described in the discussion in chapter six. Chapter six described how to apply the *Mind References* step-principles in the design of displays that assist pilots in the management of automated systems and problem solving during the flight. However, it stopped short of testing these displays, as this is outside the scope of this current research.

In modern cockpits, pilots are faced with an ever-increasing amount of information. The challenge is to deliver information in a meaningful way, drawing on the existing knowledge and natural abilities of pilots. It is a well-known fact that pilots have a high workload, which progressively increases with introduction in new equipment, reduction of crew and new responsibilities for pilots, for example, air-traffic awareness/control for commercial airlines and additional operational tasks for military aircraft. There are several tasks in the pilot's routine where the designer can minimize the pilot's time spent on a task by presenting information to pilots' in a meaningful way. One way to present information with these attributes is to use a *Mind Reference* presentation, which has been explored and tested in this chapter.

Chapter 9: Conclusions

9.1 Scope of the Mind References framework

The aim of this thesis was to uncover information related problems that pilots' have in with the glass cockpit. To identify the roots of these problems, and to find solutions to the information presentation problems to help pilots' more effectively operate automated aircraft. The resulting thesis of these studies can be regarded as providing two things: (1) it reveals how a new systematic interface design process was conceived from first identifying effective information presentation directly from the operator in their time-critical working environment; and (2) it provides a resulting framework, that serves as guidance for the interface designer on how to arrive, structure and present information presentation to a operator in a cognitively efficient manner.

This chapter brings the results of observational and empirical studies and experiments together, showing how these results provide answers for the four research questions posed in chapter one. The results show how the systematic interface design process, the method used, and the resulting framework work together. The applications and limitations of the framework are also discussed. Further, it outlines the lessons learned during this research, followed by the main contributions of this thesis. Lastly, possibilities of future applications of the framework and of the systematic interface design process are discussed.

9.2 Research Question One: Root causes of the problems pilots have with automation

RQ1 - What are the root causes of the problems pilots have with understanding and operating automated systems?

In posing this question, two directions where investigated, (a) the existing design processes, which are currently used in the aerospace domain, were examined; and (b) how pilots are trained and acquire their understanding about aircraft operation and automation.

It was found that design processes generated in the research domain are rarely followed in the industry (Newman & Greeley, 2001; Singer, 2002). Another fundamental finding was that the operators' information demands are not considered early enough in the design process to influence the final design. In fact, pilots are involved too late in the design process, such as during the evaluation and testing of the final design. At this stage pilots input on the usability of the design are too late and to expensive to implement. Furthermore, pilots who do have a chance to evaluate the design are test-pilots, who are not representative of the pilot population that will be using the final designed product.

Therefore, to understand the root-cause of information problems that pilots' experience, investigations were performed through both, the observational study of airline pilots being trained on a glass cockpit aircraft, and during their first operational experiences after training in flight. These investigations illuminated the root-causes of problems that pilots encounter during training and operation of a glass cockpit aircraft.

The root-cause of problems that pilot have with information in the glass cockpit lies on two levels, at the concept and design level, and also at the implementation level of design. During the concept and philosophy of cockpit design the manufacturers designs are not considerate to how pilots think of aircraft operation. In fact, at times the aircraft automation operates in the completely the opposite way to what the pilot expects. During the implementation of design, logical designs are not followed through throughout the cockpit, which brings inconsistencies into the cockpit. This can lead to the same information being presented to the pilot in completely the reverse manner, confusing pilots.

In this thesis, the root-causes of the problems were investigated through empirical study (RQ2), systematic design (RQ3) and the implementation process (RQ4). A method of eliciting knowledge directly from the pilots was used to understand how to support their aircraft operational practice.

9.3 Research Question Two: Method for eliciting knowledge in a time-critical domain

RQ2 - What is a suitable method for eliciting information about the knowledge of how pilots operate in a time and safety critical environment? And further, is there a method that brings valid and reliable reports on pilots' own experience?

The second research question lead to a modification of an existing knowledge elicitation method, the cued-recall-debrief method (Omodei, Wearing, & McLennan 1997). It was modified to systematically discover fundamental information structures, rules and strategies that pilots use to understand and operate the aircraft. The method did uncovered these elements and these became a basis of a framework that develops a design philosophy for automated aircraft and the design of displays that support and comply with pilots' strategies and rules of aircraft operation.

The method was a systematic approach to investigation in real-time the pilot and aircraft operation whilst not disturbing the pilot's continuous work and preserving the links in time-dependent information. The method allowed pilots to relive the flight during a debrief session, where the researcher was able to cue pilots to recall their inner thought processes from any point of the flight, and it permitted the researcher to ask all the questions required for the study without interrupting the pilot's operational environment.

The method also included an evolutionary analysis that allowed the retrieval of time-dependent information whilst preserving the links in information that the pilots use throughout the flight. It showed how to expose information that the pilots' use as references, and how to recognize the strategies that pilots' use to organise their information-space, and how they overcome existing information related problems in the glass cockpit. Lastly, the evolutionary analysis revealed a diagram of the 'Evolution of Information Flow', which showed how pilots' use information through the flight, and how the existing information structures are developed and used. It also revealed the strategies that pilots use to acquire, manipulate and monitor information in an automated cockpit.

9.4 Research Question Three: Mind Reference Framework

RQ3 - Is there a conceptual framework that helps designers and engineers compose and deliver effective information systematization and presentation throughout the glass cockpit and on individual interfaces?

In considering this question, a wide range of conceptual frameworks were examined, out of which few have considered investigating the pilot's perspective and experience of aircraft operation (e.g., a notable exception being Hutchins & Holder, 2000). None have systematically investigated pilots every day aircraft operation, apart from Sarter and Woods body of work (e.g. 1992, 1994 & 1995). Existing research has tended to focus on specific isolated automation related problems, but has not been extended to a framework that can assist designers in avoiding these problems in future cockpit development.

A systematic investigation using a modified cued-recall-debrief method was conducted in the full-flight simulator with participation of experienced pilots. As a result a Mind Reference framework emerged that consists of rules, information structures and strategies that the pilots' were observed to use to make sense of the vast amount of information they need to process in a short span of time. This framework may be helpful in design of future interfaces.

9.5 Research Question Four: Effective Information Presentation

RQ4 - What is more effective information presentation? and how can this be arrived at?

The last research question is answered through the application of the Mind Reference framework in two types of displays: the first display was aimed to provide the pilots with information that helps them manage and monitor automation throughout the flight; and second display was aimed to help pilots perform a typical calculating task faster and more accurately, relative to a typical numerical presentation of the same information.

Chapter seven provided detailed guidance of how to apply a Mind References framework in the design of a monitoring display. The framework contains intentionally ordered step-principles that guide a designer through the development of each feature on the display. They direct the designer to consider relevant rules and information structures to support pilots' information management strategies and tasks. The framework contains an Information Matrix that consists of three information classification dimensions that are characteristic of the information pilots' were observed to use. The designer is guided through the use of the Information Matrix to uncover appropriate presentation for required information, as well as to explore the links and relationships that need to be considered

The second display was designed to support a typical, for a pilot, calculating task and was designed through the application of the step-principles based on the Mind References framework established in chapter six. Chapter eight then examined the effectiveness of the information presentation on this display. The test was run on 40 experienced pilots. In this experiment the pilots' performed the task of calculating the time to altitude more than 200% faster and with significantly fewer errors using a display that was designed through the application of step-principles when compared to using a numerical presentation of information.

9.6 Application and Limitation

This thesis has shown how to apply the systematic interface design process. Within this thesis the outcome of the systematic interface design process, the Mind-Reference frameworks step-principles, have been validated through the experiment with professional pilots. As part of future work it may be helpful to validate the systematic interface design process as a whole. However, it is argued that design method validation needs to be conducted using participation of professional design engineers, therefore to gather this data requires a considerable amount of time and expense, and is out of scope of this research.

One limitation of this systematic interface design process is that it requires a considerable amount of time. However, there is a benefit in understanding operators' information requirement prior to design and providing information to the designer on cognitively efficient information presentation solutions. It can be cost effective to 'get it right the first time', and not to involve the operator too late in the design process, as is still done in the industry, when it is too late and too costly to implement recommended changes.

The advantage of the systematic interface design process is that it can be extended to understand operator information demands in most time and safety critical domains. For example NASA Ames (Johnson, W., Lee, P. U., & Battiste, V. Personal communication, 19-20 May 2005, Moffett Field, CA) are considering applying it to study Air Traffic Controllers and spacecraft operators' information demands.

The advantage, and at the same time a limitation, of one of the steps of this process, is that the use of a head-mounted camera on the operator for a cued-recall-debrief method does not require the researcher to be in the same location, as it can be either dangerous for an inexperienced person to be in that environment, or the presence of the researcher can affect the safety of the system. This method allows the researcher to study previously inaccessible domains, for example during military type operations.

However, the meaning-rich information presentation solutions the designer, or researcher, can achieve using the Mind Reference framework in design of new displays and interfaces may be either excessively demanding for a commercial-of-the-shelf equipment developer, or not readily acceptable to the industry as it does not represent an incremental advance on current technology.

Also, it must be noted that, especially in an aerospace domain, 'design does not operate in a void'. Government and industry standards regulate the degree of novelty in safety-critical domains. However, the potential benefits of efficient and accurate operator performance using complex displays and interfaces may increase overall safety and become the standard to follow.

9.7 Future Work

The Mind Reference framework can serve two further purposes. Firstly, it can show the information levels at which pilots' have problems, thus aiding the evaluation of interfaces to identify potential information problem areas. Secondly, during interface design and evaluation, it can direct the designer's attention to possible solutions for issues related to information presentation and structure. Initial work on the use of the Mind Reference Framework as an evaluation tool has already begun (Solodilova, Lintern, and Johnson, 2005).

Another area for exploration is the design and evaluation of an integrated information-space in a whole cockpit with the use of the Mind Reference framework. The monitoring display described in chapter seven has attracted the attention of C130J Hercules pilots (Deen, G. Personal communications, 18-21 April, 2005 and 14-17 April, 2003). They would like to see this display being used prior to and during the flight crew briefing, and also presented throughout the flight to maintain a shared understanding of the flight progress.

Lastly, during the experiment reported in chapter eight, it was observed that pilots' performance significantly improved between the first and last task on the display, which was designed through the application of the Mind Reference step-principles. Further research may provide an insight on whether the displays designed using this framework make operators training less time consuming.

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Appendix 1

Table 3.1: Based on 1st Debrief Transcript

Attention	**Action**	**Thought (or 'Striked me')**	**Plan**
	brakes come off		
		make sure the trim set	
	put my flaps down		
	I'm putting my throttle up to full thrust		to go down the runway
focus on keeping down the centerline	keeping the aircraft moving down the centerline		
watching my airspeed	pushing the joystick forward		to keep the aircraft on the ground until my airspeed gets over 80
	slowly easing joystick back		
	aircraft just lifted of the ground		
	starting to pull the joystick back		
to look at my artificial horizon			
building off to my left		to indicate my climb and my direction	
see where my compass is pointing			to make sure I'm traveling north
			concentrating on climbing to 2000 feet
			where I'm going to do my bank to the east
checking the altimeter			
building goes out of sight	flaps have come up		
concentrating on altimeter			
keeping my direction North			

	keeping the aircraft stable		
	slight rudder movement to keep myself facing north		
Checking the airspeed			between 60 and 80
focusing back on the altimeter			
Occasionally doing scans of the visual horizon			looking at for anything that I might run into
	I'm coming up towards 2000		I want to continue climbing through the bank
	I turn to the right and to face East		I'm want to going to keep my climb to lead to 3000
	Trying to conduct a steady turn on the 2000		
		I have in fact ended up loose a bit of climb on the turn	
, having to make adjustments to that (lose of climb)			
focusing on the compass			
			make sure that I line up East
	I over turned		
	so had to make minor adjustments… on the easterly setting		
focusing that I've got the same climb angle			
and focusing on my altimeter			keeping me going to the east
the compass			
		need to check the clock	
			when I do my next turn at 3000 to go South
			want to make sure that I travel south

			for 3 min
glancing across the clock			
			planning to level out at about 3000
		I have a tendency to continue climbing when flying on the straight	
	I've started turning a little bit early		
focus on the clock			hopefully level out at 3000
		During the bank actually lost a bit of altitude	
	made it to 3000 during the bank		
concentrating on the compass			to get my barring to the South
	using both joystick & rudder to do the turn		
keeping an eye on the speed			
	I'm flying south		
	I've cut the engine back a bit		because I should be turning just over that … to the South of that building
Not enough time has elapsed…			…Not enough time has elapsed for me to do to initiate that turn
			I've started to think about my next maneuver when it gets to 3 min
			which will be to shut the throttle off, put the nose down & dive to the west
I see my altitude … 3000			
		I've realized I'm	

		quite a bit further south	
		because I’m normally taking the throttle a little in prior to this	
			know my approach to the runway is going to be longer …
			…so therefore my descent rate has to be less
	pushed the throttle in		
	commenced the steep dive		
keeping an eye on the airspeed			
		I don’t want to stall in a dive	
my pitch/roll angle			I could descent to 2000
focusing also on the compass			
			I’ll line up on the west first
focus on the altimeter		I can get to the west quicker than I can loose a 1000 feet	
			I’m now starting to think about what type of throttle setting I’m going to need once I do my next thing to the north
			I’m going to need quite a bit of throttle in to get all the way back to the runway
		I come around to 2000 feet	
checking my airspeed			

checking it's nice & high			
			. I'm about to do another steep bank to the right
	I turned to the right		
			I'm going to start looking on the horizon for that runway
I'm using the wind to give me an indication of what the speed			
There is the city & there is the runway			
		I haven't got quite far enough west to line up with the runway	
	I've readjust the aircraft		
	I'm aiming off		
Checking my airspeed		I'm not losing too much altitude	
	Start putting the flaps down		right down (flaps) so that I can get maximum amount of lift
		plane is handling like a cow, because my airspeed is still quite low	
		but I'm not going to stall	
	I put a bit more throttle on.		
		I'm also a long way out	
			I can't do my normal approach landing from here.
		reminding myself that the airfield is at 600 feet of sea level	
			So I'm not to look

			for zero altitude when landing
	Bring the aircraft round now	I'm basically lined up with the strip	
my altitude and the airspeed		My major concern now is my altitude and the airspeed	
possible collision items			
can see that blimp up			deciding that there is no chance I'm going to run into that
	I'm coming down		
		I'm realizing that I'm probably about 200 feet below where I want to be	
			deciding when I should increase the throttle to get in there
	increase the throttle		
		runway is so long	I'm going to aim for the center of the runway
			just land short on the runway
	I'm doing my best to maintain very gradual descent		
	I line up on the runway		
	Rolling the aircraft from side to side to give me a bit more visibility		
visibility of the buildings & the runway			to judge my distance out
		At this point I'm realizing that I'm definitely to low	
	increase the throttle		
Concentrating on lining up	starting to pull the throttle back		
	I'm going rolling…		

so that I can see the runway	bringing across to the right		
	Lining up on the center		
looking at where the sea meets the sand			give me a good indication when I'm over the runway
		definitely still too low	
looking at the altimeter		I'm not loosing much altitude	
	keeping as steady as I can		
	Trying to get back on to the glidepath.		
		Realizing that I'm not going to make it	
Looking out to the left			
		I'm still over water	I expected that to be just coming over the sandy beach
	Increase throttle a bit		
Altitude	Just trying to maintain enough altitude		
	Drop on the front of the runway		
	Throttle off		
	Touch down		
	Put the brakes on		
			I try to keep the aircraft moving down the runway.
	the aircraft moving down the runway.		
Attention	**Action**	**Thought ('Striked me')**	**Plan**

Appendix 1

Table 3.2: Analysis of Flight Stages based on the 1st Debrief Transcript

Down the Runway	**Take Off**	**Climb**	**Climbing Turn**	**Climb**	**Climbing Turn to level out**	**Level Off**	**Slow down**
Brake come off	Easing the joystick	Concentrating on altimeter	Approaching 2000	Focus on climb angle	Turning	Flying South	Cut the engine, "I should be turning South"
Trim set	Pull back on the joystick	Keeping direction	Turn right (East) & climb to 3000	Focus on altimeter	Focus on the clock	Taking note of time	Checking the clock
Flaps down	Look at artificial horizon	Keeping airplane stable	Conducting steady turn	Going East	Climbing & banking	Keeping South direction	Think of next maneuver
Throttle up	Look outside for climb & direction	Rudder movements for North direction	Make adjustment in climb & turn	Focus on compass	Concentrating on compass	Watching the clock	Watch the altitude
Keeping airplane centerline	Look at compass, traveling North	Check airspeed between 60 & 80	Focus on compass	"Check the clock on the next turn at 3000 to travel 3 minutes."	Get barring South	Look outside – navigation	"I'm quite a bit further south"
Watching airspeed for 80	Climbing to 2000	Focus on altimeter	Line up East	Look at clock	Use joystick & rudder to turn	Checking height	"know my approach is going to be longer…"
Joystick forward	"Where to bank to the East?"	Look outside	Minor adjustments to on East heading		Keep an eye on the speed	Readjust, put the nose down, loose altitude	"…so therefore my descent rate has to be less"
	Check altimeter					See building	
	Look outside					Calculating how far I'm	
	Flaps up					I've been traveling faster than usual	

Turning Descent	Descent	Turning Descent	Final Approach	Last adjustments before touch down	Touch down	Rolling down the runway
Push the throttle back	Focus on compass	Turn right	Aim on the runway	Lining up	Drop on front of the runway	Keeping centerline
Steep dive	Line up on West	Look outside for runway	Check airspeed	Throttle back a little	Throttle off	Braking
Keep an eye on airspeed	Focus on altimeter	See the city & runway	Loosing too much ALT	Look outside	Touch down	
“Don’t’ want to stall.”	“what throttle setting I need to the north?”	Adjustment on runway line up	Flaps down	Lining up on the center	Brakes on	
My pitch & roll angle	“need quite a bit of throttle”		Hard to maneuver the plane	Look outside		
Descent to 2000	Checking height		“I’m not going to stall”	Look at altimeter		
Focus on compass	Checking airspeed		Put more throttle	Keeping steady		
			“airfield is at 600 feet of sea level”	Back on glidepath		
			I’m lined up	Look outside		
			Check airspeed	Increase throttle		
			Check altitude	Check altitude		
			Look outside			
			“I’m low”			
			Increase throttle			
			Aim for center of runway			
			Maintain gradual descent			
			Lined up with runway			
			Rolling aircraft from side to side to look outside			
			Judge distance out			
			Increase throttle			

Table 3.3: Continuous flight analysis

APPENDIX 1

Timeline

0:35.00 – 0.35.53

Situation

- approaching 3000
- leveled out early
- commenced bank to the South

Present Action

- banking aircraft to the right
- leveling out
- scanning instrument panel & outside environment

Using…

- joystick
- rudder

Info required

- altitude
- angle of bank
- angle of attack
- compass/ direction
- timer
- landmarks
- airspeed

Future Action

- leveled out
- keeping the altitude
- flying fast for 3 min

Modified info with respect to future action

0:40.03 – 0;41.28

Situation

- traveling south at 3000 feet, slightly climbing
- maintaining high speed

Present Action

- checking the timer
- judging height in relation to airfield
- reducing throttle
- scanning instrument panel & outside environment for ref points

Using…

- joystick
- rudder
- throttle

Info required

- altitude
- angle of bank
- angle of attack
- compass/direction
- timer
- airspeed vs. stall V
- rate of descent
- outside environment
- landmarks/ proximity to airfield

Future action

- descent when 3 min is up i.e. point aircraft nose down
- cut the engine off
- turn to the west
- loose altitude fast to 2000

Modified info with respect to future action

0:46.37 – 0;48.20

Situation

- aircraft descending to 2000
- turning West

Present Action

- pushing aircraft's nose down for slow descent
- banking right
- adjusting throttle
- scanning instrument panel & outside environment

Using…

- joystick
- rudder
- throttle

Info required

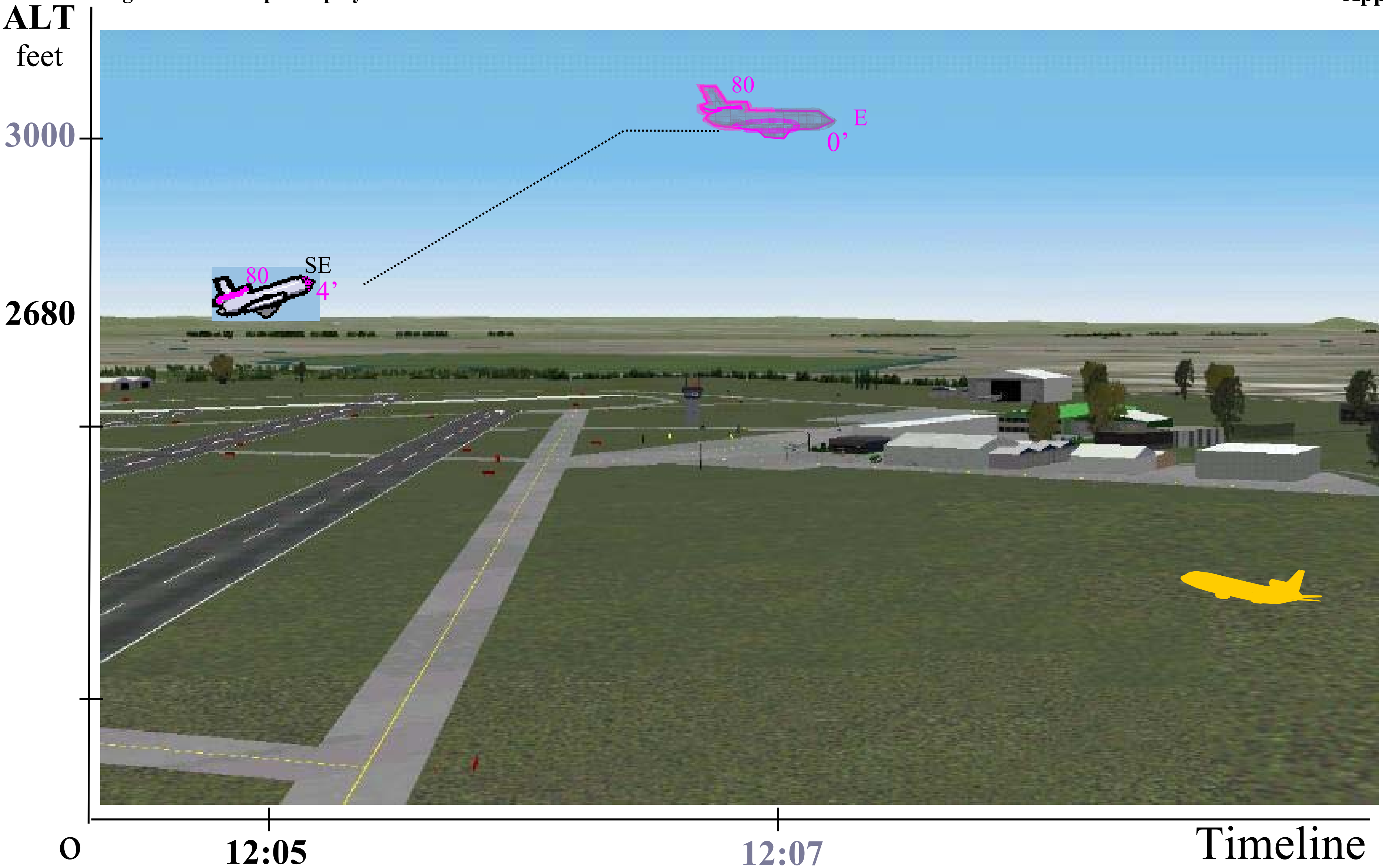
- altitude
- angle of bank
- angle of attack
- compass/ direction
- airspeed vs. stall V
- rate of descent
- outside environment
- airfield
- flaps indication

Future action

- rolling out of the bank to the West
- adjusting aircraft's attitude
- turn to the west
- pulling nose up closer to 2000
- starting another 90' descending turn to the North
- searching for airfield
- dropping flaps at low airspeed

Modified info with respect to future action

Figure 3.1: Example display



PILOT Centred Problems

Aircra	Fea	Role Change	Over-confidence	Under-confidence	Understanding	Use	Manual Skill	Automation Awareness	Situation Awareness	Focus of Attention	Workload
C130J	pitch alert				4. IAS mode places FD in speed on pitch mode, i.e. speed is controlled by pitch, and is incompatible with A/T PROBLEM: (a) IAS came from old conventional aircraft and could be used in climb/descent and level flight, but here it can only be used in climb or descent and incompatible with level flight (b)IAS is associated with control of speed, but here IAS mode is a vertical mode (c) IAS, the speed related mode, is incompatible with A/T	SUBHEADING: Pilot may over rely or underlay on automation due to poor understanding, poor interface design and automation logic and function presentation. Hence this category should be a higher category.		3. A/T modes have a table 16x16 on priority of modes PROBLEM: Poor way to present to pilots the logic priority of A/T modes (see A/T table for examples) i.e. as it appear from the table 'HOLD' modes have no priority, but ALT HOLD will disengage ALT SEL, VS, IAS and has a priority over PITCH HOLD	1. Pitch recovery - Chevron pairs ^^ indicated that the nose is high. PROBLEM: (a) Contradicting to FD philosophy 'Fly towards' (b) Too similar to Chevron ^ indicating that the nose is low		11. Representation of information in a different dimension than the rest of the display PROBLEM: PFD does not show graphically distance, it is done on NAV display. However this PFD has 'CAPS distance tape' (see figure 18D2) showing how far behind or ahead of the target the aircraft is
C130J					16. CNI-MU have no clear logic in structure of pages and structure on the pages for pilots to follow PROBLEM: Pilots find it difficult to navigate through the CNI-MU pages			15. Mode change may not occur when supposed to PROBLEM: In any climb mode selected NAV or ALT mode may not capture course (NAV) or altitude (ALT) and go through present parameters if there is a deviation. The altitude will only be captured within 10% of the rate of climb and the course will be captured only within 5% of the target course. These information is not announced to the pilot	27. Absence on the same information on similar displays PROBLEM: AGL information is only displayed on the HDD and not on the HUD SOLUTION see note 27		12. Wrong association of information may occur PROBLEM: Speed Error Tape is located on the same side, left, as the Airspeed Indicator, but CAPS Distance Tape is located on the side of the Altimeter and VVI. This allows for possibility of interpreting the CAPS Distance Tape as Altitude deviation instead of distance deviation (see figure 18D2)
C130J								20. No clear guidance to show which AP or FD modes are engaged PROBLEM: It is the same annunciation on PFD and Reference Set/Mode Select panel; apart from alphanumerical annunciation on Mode Annunciation Panel			13. Information interpretation may be wrong PROBLEM: When the CAPS Distance Tape is below the Climb/Dive Marker the aircraft is ahead of its target and visa versa, however the Speed Error Tape indications are reverse if it is below the Climb/Dive Marker than the speed is behind or low of required speed and if above the speed is to high (see figure 18D2)
C130J								22. Automation modes are not traceable, observable or predictable at all times PROBLEM: This does not allow the pilot to be ahead of the plane, which is the basic rule pilots must follow to successfully fly any aircraft SEE pc 45 (Sarter and Woods, in press p. 4)			
C130J								25. Automation response or not response are not as expected PROBLEM: The pilot tried to engage the APPR too early, the NDB was not….??? and automation did not allowed that, but gave no feedback why			
C130J								34. Automation logic is not clear PROBLEM: (a) During an ILS in APPR mode, there are courses back and front that can be captured on interception. There is no clear logic what determines when the aircraft intercepts and whether it should have intercepted the course already, and which course back or front it is going to take. None of the above information is announced and it can only be monitored by a pilot (b) Some automation modes are mutually exclusive and can not be selected at the same time or will disengage other modes and have a priority over them			

777		37. Logic discrepancy and too many conditions, 'ifs' to remember PROBLEM: If the speed is above 80 knots, if FD is on and if LNAV and VNAV are armed, pushing the TOGA switch would disarm the LVAN and VNAV. However pushing TOGA switch twice set the throttle at full thrust.	36. Automation logic is not clear PROBLEM: during take off if LNAV or VNAV modes are armed, the push of a TOGA switch will disarm LNAV and VNAV, leaving the pilot without the navigational data for automation to follow	50. Mode Annunciation on PFD is inadequate to reflect the automation mode change PROBLEM: Once mode is changed it flashes for 10 seconds in a new mode alphanumerical format. However if the pilot is busy with other tasks for the same amount of time that change can be missed	
777		39. Automation use logic PROBLEM: APP button can not disconnect APP mode, if LOC and G/S engaged. The pilot first have to disconnect the FD and only then the APP button to disconnect the approach mode	47. Mode annunciations may be misinterpreted PROBLEM: During a take off run the autothrotle can not be changed until the aircraft reaches 80 knots per hour. Then the autothrottle goes into HOLD mode announciated on PFD. It can be altered after this annunciation. However the word 'HOLD' may be misinterpreted as autothrottle is 'on hold' and can not be altered		
777			49. PFD mode annunciations may be misinterpreted PROBLEM: VNAV PTH - means that navigational information is taken from Flight Management Computer VNAV ALT - means the navigational information is taken from Mode Control Panel VNAV SPD - means that restrictions from Flight Management Computer are not accounted for		
A320	56. The use philosophy for a Flight Director is 'to fly towards' the Flight Director sign but other features of the same display are to used in a different way PROBLEM: The 'bouncing ball' on the speed tape indicates that the speed is too high and needs to be reduced. However according to 'fly towards' philosophy that applies to other features in this display would indicate to pilot to increase speed instead of decreasing		22. Automation modes are not traceable, observable or predictable at all times PROBLEM: This does not allow the pilot to be ahead of the plane, which is the basic rule pilots must follow to successfully fly any aircraft SEE pc 45 (Sarter and Woods, in press p. 4	62. ECAM display information is inconsistent PROBLEM: Related fuel information is located in different pages of the ECAM displays. 'Fuel USED' is on a separate page from 'FOB'.	61. Altitude tape scales are not the same PROBLEM: the Altitude and the Vertical speed tape are different in scale.
A320			53. Mode will not engage if some data is not entered PROBLEM: During take off SRS mode will not engage if one of the reference speeds were not entered into MCDU	87. Most of mode changes, especially mode reversions are vertical PROBLEM: However there is no vertical representation of changes on displays, apart from an altitude tape on the Primary Flight Display and altitude restriction on the NAV display	
A320			54. Mode annunciations do not reflect well the behaviour of automation PROBLEM: When the pitch modes control the speed it is not reflected in the alphanumerical name of the mode, for example CLB or EXP DES		

A320	68. Automation has a different strategy to the pilot PROBLEM: When the pilot would like to increase the rate of descent, the pilot would use speed breaks. In case of automation when Vertical Speed or Flight Path Angle mode are engaged pilots are advised not to use speed breaks, because that would lead to an increase thrust, i.e. what pilot do not want
A320	69. Automation has a different strategy to the pilot PROBLEM: When the pilot would like to have a high rate of descent, the pilot would not select high speed on throttles as an option. However, the automation in order to have a high rate of descent requires a selection of high speed on autothrottle, and speed breaks.
A320	70. When some data is not entered into the systems prior take off the mode will not engage PROBLEM: The FLEX TO mode will not engage during take off if: 'In FLEX TO limit mode with levers in FLX TO/MCT detent provided a FLX temperature has been entered on Multipurpose Control and Display Unit (take off page).'
A320	71. Pilots have to rely on memory to remember conditions under which automation will or will not engage PROBLEM: If Flight Director is off the pilot can not have managed speed, only in APPR mode the pilot can have managed speed without the Flight Director.
A320	72. Automation has a different strategy to the pilot PROBLEM: During descent the pilot controls speed by pitch, but the automation controls speed by thrust
A320	73. Pilots have to rely on memory to remember conditions under which automation will or will not engage PROBLEM: To engage HDG/ TRK the pilot has to wait for 5 sec after lift off before engaging it, but HDG/TRK has to be preset before take off and up to 30 feet, otherwise NAV mode engages and at 30 feet RWY TRK will be announced
A320	74. Airbus automation philosophy states, '…automation system does not work against a pilot input.' PROBLEM: Mode reversions happen as a result of automation 'disagree' with pilots' input (see Mode Reversion extract from the manual). One example is when the pilot enters a new altitude which is below or above during climb or descent respectively and automation rejects it and proceed in the direction opposite to what the pilot selected

A320	75. Although that FMGS mode logic says that mode 'reversion does not modify the aircraft behaviour' (FMGS 1996, section 28), it actually does and it also changes aircraft state and conditions under which it operates PROBLEM: Conditions: Mode reversion due to change from NAV mode to HDG/TRK not only discard all speed and altitude restriction, but it also changes how it controls the speed. Behaviour and state: From original DES mode where the automation controlled speed by thrust, it is now in a V/S mode and controls speed by pitch
A320	76. The annunciation of mode reversion is salient PROBLEM: Once the mode reversion occurs the new mode is announced to the pilot, flashing for 5 seconds. However if pilots were involved in other tasks, this might be missed
A320	77. Automation engagement implies a sequence, which might not be obvious to the pilot PROBLEM: The pilot must have some speed mode before activating the APPR mode, otherwise automation does not have a speed reference to fly the approach
A320	88. Automation behaviour may not be apparent PROBLEM: In TOGA mode, executing a go around and THR CLB mode is flashing, changing autothrotle will only bring it to idle or previous speed, which is the opposite to what the pilot wants, i.e., a full power on thrust. ??? WHAT TO DO TO AVOID THIS ??? Only when reached accelerated ALT.
A320	90. Rules to remember to avoid surprises PROBLEM: ATHR will not engage below 100 feet, if Flight Director and Autopilot is disengaged
A320	91. Automation may have misleading mode names PROBLEM: Speed Reference System (SRS) mode is actually uses a pitch guidance to maintain speed. Despite the fact that it has the word 'speed' in the name of the mode, it is a vertical mode (Airbus manual, Vol. 1, p. 22-30-1)

Aircraft	Feature Analyse	Functionality (capabilities and limits)	Automation Failure	Human-centred Design	Automation Authority	Complexity	Automation Levels	Pilot/Automation Interface	Standardization	Air Traffic Control	Use Philosophy
		Automation Centred Problems									
		description of intended function and limits	instances when	does this represent a	does the feature		is the feature active at	is the representation to the pilot logical and clear.	consistency, etc..	n/a	Automation USE PHILOSOPHY may be lacking
C130J		18. Automation does not warn the pilot about aircraft limitation PROBLEM: The aircraft is flown manually on descent with Autothrottle set to 170 knots. The aircraft is in a steep descent angle and gained speed to 190 knots. Pilot has to remember to raise the noise of the aircraft to slow down to 168 knots, which is a limit on landing gear down, in order to put the gear down			21. HEADING: Hard to separate responsibility, function of where automation function ends and pilots' responsibility begins PROBLEM: see problem 19	2. FD modes are oversimplified PROBLEM: (a) FD modes both lateral and vertical are called APPR (b) SEL mode is too ambiguous; it could apply to heading, altitude and speed for example, but here applicable to altitude	17. Automation permits to break aircraft limitation PROBLEM: It allows to overspeed with gear down	5. Button on the Ref/Set panel do not directly correspond to annunciation on Mode Annunciation Panel and PFD PROBLEM: SEL ON button on REF/SET Mode Panel vs. ALT SEL annunciation on PFD Example the selection is different to annunciation, hence difficult correspond one with another			
C130J		33. Automation actions are not the same as pilots expect PROBLEM: On final approach the push of a go-around button does not engage throttle as the pilot would expect.				19. Did not set up mode properly PROBLEM: The aircraft shot through track at which the aircraft should have captured the direction of the next manoeuvre and the consecutive mode, NAV, did not engage		8. HUD presentation of speed and altitude in a ten-doted-circle are exactly the same (see figure… HUD) PROBLEM: Confusion happens when close to the ground and indications are the same, monitoring becomes confusing	6. Order of information annunciation differs, selection vs. annunciation PROBLEM: (a) on REF/SET Mode panel the order is in the 1st raw ALT, SEL, HDG, NAV, APPR, 2nd raw VS, IAS, CAPS, A/T, vs. PFD instrument position order - 1st raw Speed, Artificial Horizon, Altitude, Vertical Speed, 2nd raw ILS data, Compass, TCAS and NAV data/source (b) same REF/SET Mode Panel order (see above) vs. Mode Announciation Panel AP ON AP DSNG PITCH OFF LAT OFF NAV ARM NAV CAPT GS ARM GS CAPT GO ARND BACK LOC CAT2 ARM CAT2		
C130J						29. Too many ways (a) to enter information; (b) to announce PROBLEM: (a) FD information displayed on - PFD-HUD, - PFD-HDD, - Mode Annunciation Panel, - NAV-RADAR display (b) FD can be manipulated from - REF/SET mode panel - Control Wheel button - AFCS Control Panel - navigational inputs through AMU and CNI-MU		9. Selection and annunciation of automation mode are far apart PROBLEM: REF/SET Mode Panel is located away from Mode Annunciation Panel where selected modes are announced	7. Use of colour may have different meaning even on the same display PROBLEM: (a) PFD mode annunciation - YELLOW for OFF modes; WHITE - for ARM, AP, HDG, VS, IAS, GO ARND; GREEN - for CAPT, CAPS, CAT2. Then HDG, VS, IAS, GO ARND also should be green colour, because they are working modes, like CAPT modes		
C130J								23. Mode Annunciation Panel design can be misunderstood (see Mode Annunciation Panel) PROBLEM: (a) there is no particular order to the arrangement of indications (b) same colour used for different type of function annunciation, for example CAPT, DSNG, CAT2 are the same colour (c) no consistency in location of similar function indication, for example DSNG and OFF switch	14. 'Fly Towards' philosophy is not followed on the same display: see problems 11, 12 and 13 PROBLEM: Most symbols in the center of the Flight Path Indicator (see figure 18D2) comply with FD, have a philosophy 'Fly Towards', for example G/S Deviation Indicator complies to Fly Towards philosophy. The Speed Error Tape, Acceleration Cue and CAPS Distance tape do not comply with it. For example if Speed Error Tape is below the Climb/Dive marker and pilot would fly down it would have an unwanted effect, the aircraft would increase speed. As for CAPS Distance Tape, if pilots would follow the tape the aircraft would deviate from the current altitude, but not have a required affect on distance.		
C130J								24. Buttons on REF/SET mode panel do not always correspond to the announcement on the Mode Annunciation Panel and PFD PROBLEM: (a) select button NAV ON on REF/SET panel announces NAV ARM, but button APPR ON on REF/SET panel announces GS ARM (b) SEL NO button selects an ALT SEL mode on PFD			
C130J								26. Information location differs on the similar data display PROBLEM: QNH data location varies between HUD and HDD			
C130J								28. Same information presented on similar displays in a different format PROBLEM: (a) on HDD altitude and speed are presented in tape format, but on HUD it is in an analogue format (b) on the HDD compass is presented in an analogue format, but on HUD it is in a tape format			

C130J				30. Same information located in a different place on a similar display PROBLEM: CDI information is located in the bottom middle of the HUD and in the bottom left corner on PFD
C130J				31. Same information represented in different format and in a different location PROBLEM: Compass in a analogue format at the bottom of the PFD, but on the HUD it is in a tape format and at the top of the display
C130J				32. Poor placement of important data PROBLEM: QNH information is away from altitude information and DME information is away from the rest of navigational data
777	44. The information presented does not always present what the pilot expects PROBLEM: Pilots are not advised to follow FD cue at take off, because it is incorrect until the aircraft takes off	42. Automation has too many levels PROBLEM: Navigation Display contains different levels of information that contain various types of information. Some levels of information do not have and can not display some types of information. For example some navigational display mode do not display point to point route legs or holding patterns	40. In case of takeover from the automation into a manual operation the pilot might not be aware of all the actions that the automation is performing PROBLEM: In Autoland LAND3 mode if the crosswind is present the runway alignment starts at 500' to 200' radio altitude but the correction of crosswind is not annunciated to the pilot	35. Mode Control Panel layout PROBLEM: FLCH mode button is located under IAS indications, but it relates more to ALT indication, more to the right
777	45. The similar switch works differently on Mode Control Panel PROBLEM: The ALT has a switch that can be switched on auto or on 1000. The auto indication means the switch has a rate sensitive rotation. However the same auto switch on the bank indications means the bank is limited by the Autopilot and setting that was set by the same switch	43. TOGA switch has too many functions, too many conditions, where TOGA switch and the times it is pushed would have a different response PROBLEM: (a) if FD is off and the speed is above 80 knots the push of TOGA switch will pop up the FD cues on PFD (b) once airborne to cancel the thrust limit derate need to push TOGA switch (c) in approach need to push TOGA switch to reenable ILS tuning (d) second push on TOGA switch sets a full thrust. It contradicts the rest of the push button logic, generally pushing the button one would engages the corresponding action and the second push would cancel the action, but the second push of TOGA switch instead set the thrust to full		38. The layout of information on PFD is not consistent with the layout on MCP PROBLEM: The instruments on the PFD are in the following order - Autothrottle, Heading, Altitude and Vertical Speed, but the order on MCP - Autothrottle, Heading, Vertical Speed and Altitude. The Vertical Speed and Altitude are in different order although the selection of data on MCP is reflected on PFD, hence would be better in the same order
777		46. The mode selection is not straight forward PROBLEM: To select CLB THR mode the pilot need to engage FLCH or push CLB CON		41. Not all selections are annunciated PROBLEM: Authrottle selected on MCP is annunciated on PFD, but the selection for example of LNAV and VNAV are annunciated on PFD
777		48. Same button has contradicting functions PROBLEM: Pushing the ALT switch on the Mode Control Panel executes the altitude entered, but the same button also deletes the altitude restrictions entered in Flight Management Computer		51. Button labels are not consistent PROBLEM: Air Bleed overhead Panel has two rows of buttons. All buttons are divided into two parts and each part of the button is lit up with the current selection. The top raw had 'AUTO' lit up on the top part, the bottom raw however has 'ON' sign at the top on two buttons and one button had the 'AUTO' sign. Moreover all of the buttons have an 'OFF' sign on the second part of the button. The problem is that the pilot can only see the lit up selection and can not see the other half and if the pilot would choose to follow the signs on the rest of the buttons, the pilot can mistake what he expects to see once the button is selected.
777		52. The mode selection is not straight forward PROBLEM: When APP button is pushed on Mode Selection Panel LOC and G/S modes are annunciated on the PFD		

A320	58. Misleading messages on MCDU PROBLEM: "Always wait 1 minute **after** the 'PLEASE WAIT' message disappears from the MCDU before engaging or re-engaging the FDs and the AP to the reset FMGS."	92. Similar buttons have contradicting functions PROBLEM: Flight Control Unit has similar buttons that set engage selected mode by pulling the knob and managed modes by pushing it. However by pushing the V/S and FPA knob also executes the level off and returns a value to zero.	5. Button on the glareshield FCU panel do directly correspond to annunciation on PFD PROBLEM: To select the desired mode pilot have to remember which combination of buttons adds to for example a THR CLB	64. Order of information presented differs on the same display PROBLEM: On the PFD the automation mode annunciation is in the following order: Speed, Vertical and Lateral (heading) mode; however instruments are in a slightly different order Speed, Heading/Attitude, Altitude and Vertical Speed. The mode places are switched otherwise would have the same order as the instruments.
A320	78. Systems tricks and 'ifs' to remember PROBLEM: 'FMGS may display temporaty erroneous predictions that can affect various data such as ECON speed/MACH, optimum flight level, fuel or time predictions. If erroneous predictions are observed: On ground or in flight - re-enter the same cost index to restart a computation', but in brackets it says, (in descent or approach, a cost index changes does not restart the computation) (a) how does a pilot supposed to trust the automation if such errors might occur (b) how does the pilot identify an error, if he/she trusts the automation (c) on top of the above problems, the pilot has to remember if there are other conditions under which such action will not fix the problem.		9. Selection and annunciation of automation mode are far apart PROBLEM: FCU is located away from PFD where modes selected on FCU are announced	65. Order of the same information presented differs in the cockpit PROBLEM: Flight Control Unit order is Speed, Heading, Altitude and Vertical Speed; Primary Flight Display mode order is Speed, Vertical and Lateral (heading) mode; but it does not match the order of instruments Speed, Heading/Attitude, Altitude and Vertical Speed.
A320	83. Conjunctions of mode may have unexpected behaviour PROBLEM: 'When expedite mode is engaged, the system disregards speed limits and speed constrains no matter what lateral is engaged.' However when lateral mode, NAV, is engaged it supposed to account for speed limits and speed constrains		10. Engine indications on the ….. Displays are in unnatural order PROBLEM: On engines displays engine 2 is on the left and engine 1 is on the right, which is different to actual position. If facing forward in the cockpit, engine 1 is on the left and engine 2 is on the right.	66. Same information does not have a consistent place PROBLEM: (a) Autopilot, Autothrottle and Flight Director initiation buttons are too far from each other on the Flight Control Unit to be related to each other. (b) Autothrottle is also away from the Speed selection. (c) On the Primary Flight Display all these annunciations are clamped together
A320	84. Limitation of the system PROBLEM: 'No step can be inserted in an alternative plan'. The alternative plan is the one that is likely to need alteration depending on the circumstances.		55. The Flight Director symbols can be misinterpreted PROBLEM: Flight Path Angle should not be used in climb, because the climb will be too low. It should be used to level off	
A320	86. Limitations of mode use PROBLEM: ALT* can not be used on descent otherwise aircraft becomes locked until the altitude is captured and the mode can not be changed		??? 57. Entry in the MCDU is not straight forward PROBLEM: The speed data is entered under the vertical flight plan, but the speed restrictions are under the speed restrictions	
A320	89. Automation behaviour may be unexpected PROBLEM: -AUTOMATION AWARENES? In climb if ATHR is engaged will come back to approach speed, which will be to low, especially if this happens during a go-around		59. Inconsistency in information being displayed on MCP PROBLEM: When the managed mode is engaged the window with the numerical value is dashed and in the selected mode the actual value is displayed in the window. However the altitude value is always displayed, even if the managed (from the flight plan) mode of altitude is engaged. It can be particularly deceiving when mode reversions happen. In this case the pilot enters a new altitude, but the automation does not accept the new altitude and does not follow it. The altitude window however still displays the value that the aircraft is not following.	
A320			60. The managed mode information is not clearly annunciated and spread over the cockpit PROBLEM: When the managed (from the flight plan) mode is engaged the value is dashed in the relevant MCDU window. To find out what value the pilots has to find out from PFD or MCDU	
A320			63. Symbology is not intuitive PROBLEM: The Non Directional Beacon symbol is a triangle, that looks like an arrow, but the beacon itself does not provide the direction.	

A320	67. Related controls are spread over the cockpit PROBLEM: Controls related to establishing an automated approach are located away from each other on the Flight Control Unit. The Flight Director (FD) and Instrument Landing System (ILS) buttons are away from Localiser (LOC) and Approach (APPR) buttons with AP and A/THR
A320	79. Entry of data has rules PROBLEM: Direction/velocity must be entered simultaneously. The previous entry will be completely overwritten even if the pilot enters only one data point
A320	80. Trick to bring up specific pages of Multipurpose Control and Display Unit PROBLEM: To activate the secondary plan the pilot has to switch to HDG mode from NAV mode in order to have a prompt to activate the secondary plan
A320	81. Discrepancy in proposed logic PROBLEM: During a go around operation 'Whenever LOC*, LOC, LAND, FINAL or GA modes are engaged, the HDG present is available. If the pilot rotates the HDG/TRK knob to set the value, it will remain displayed in the window'. However, according to philosophy when managed modes are engaged the HDG/TRK will remain dashed and the new selected value will only be displayed for 5 sec and then disappear.
A320	82. Different buttons engage the same mode PROBLEM: 'The pilot pushes the 'APPR' pushbutton on the Flight Control Unit to arm or engage the localizer and glide slope or 'FINAL APP', depending upon that approach type he had inserted in the flight plan. The 'LOC' pushbutton arms or engages only the localizer mode.' (Airbus manual Vol. 1, p 22-30-1) APPR pushbutton 'arms, disarms, or disengages the approach modes: LOC and G/S modes if an ILS approach is selected in the active F-PLN. APP NAV-FINAL modes if a non precision approach is selected in the active F-PLN.'
A320	85. Information does not have a constant location and the pilot is required to remember the location of required information PROBLEM: 'No predictions are displayed for the selected alternative on flight plan pages, but the pilot can read ALTN trip fuel and time on the INIT B page before engine start, and estimated time and estimated fuel on board at alternative on the FUEL PRED page after engine start.' (Airbus manual Vol. 1, p 22-20-27)
A320	93. Hard to differentiate which mode has a priority PROBLEM: Currently there is not indications which mode has a priority, for example how can the pilot identify which mode, vertical or autothrittle controls the speed.

Appendix 3

C-130J Observation Study
24/10/01 09:30
Debrief tape 1
Automation

TIME LINE	SEQUENCE OF EVENTS:	DIALOG	UNDERLYING PILOT'S REFERENCE SYSTEMS	COMMENTS - DEBRIEF	GOALS:	FROM -TO		ACTION/ MONITORING/ PLANNING:	OBJECTS USED:	NOTES
00:00	FLIGHT PREPARATION (Setting up the cockpit)		*Structure of checklist,* i.e., - adapting around cockpit problems; - possibly that's a structure that pilots thinks in?)	'In the preparation what I'm doing is preparing the cockpit for the standards that we have in our checklists.'	Displaying reference maps		A	Locating, folding & placing maps for good accessibility during the flight	Paper location reference maps	
					Displaying T/O charts		A	Locating & placing charts on control column	Paper charts	
01:10	*Airplane Forms*: Data Entry		Imposed structure on T/O procedure by CNI, of in which order to input information	'I'm looking at the CNI at the moment to insure that all of the different functions with in COMM/NAV interface are set for the T/O, so I'm sequential going through the buttons, checking that we have the right NAV aids tuned; that we have the right communication frequencies tuned, the identification box is set up correctly.'	Data entered for the whole flight (as much as possible)		AP	Programming the system from T/O to landing	CNI	
02:10					Radio data entry			Programming radio frequencies	AMU	
02:30					Navigational data entry			Programming navaids	AMU	
03:35		Rhythmic		'That was a navigation tune. It's not realistic in the sim. Normally it's just one switch selection & everything is preset for you'	???			Working through	CNI	
04:00			@ Does actually CNI calculates? Or it's a system inside/computer that calculating	'Checking the T/O & landing data is correct. You might actually see me flip trough my book see if my T/O & landing data, check the speeds, for what weight we are at & that way it's checking the calculation of the CNI to insure that's correct. Then I will check the route that we have, put in the box & that way we check that against our navigational charts to make sure that distances & tracks we have on those match up to what the COMM/NAV interface gives us. That way we will know when we engage the automation will give us the correct path for us.'	Keeping aircraft in balance		AP	Programming weight/balance parameters, including take speeds	From papers tables data entered & into CNI (crosscheck)	

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				'So realistically having that route in there is good for automation, but if you are doing a short leg you can do it without that sort of stuff in, but makes the workload a lot higher.' 'The landing data includes threshold speeds and approach speeds per flap setting. So if I was with 0 (zero) flap there will an approach speed & a threshold speed & what I will be looking at for are those on finals is to try and aim to hit those speeds. The approach speed I will fly all the down until I get close to the threshold & then I pull a little bit of power off, have the speed dribble back until I hit my threshold speed over the threshold 350ft; & then from there I pull my throttles back to flight idle & speed will decay to a touch down speed. Those speeds are already pre-calculated in the CNI & by me doing it I'm checking that they are correct, if they are not correct, we are possibly flying slower then we are required to be for that weight.'						
04:44					Same information among the crew			Cross-checking	Outside runway direction	
05:00				'Different ways that we can access NAV aids one through the CNI & one through the COM/NAV interface, which is just on the glare shield. Certainly when we are flying I prefer to enter at the top, because gonna still be looking out. Whereas as soon as your heads down, you are back to a one-pilot cockpit.' 'Ye, just checking a setup that it's all right. Now I'm setting all of my avionics. I will be using the boxes under the glareshield there to insure that I've got the correct screen selected there then it's going to give me information relevant to what I'm doing directly after take-off there.'			A	Adjusting NAVvaids		
04:40	*Briefing:*				Cross-reference of information between the crew		AP	Cross-checking for the right reference information (i.e. date of issue, airport, runway, direction,	T/O paper plates	

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								navpoints along the route, distributing workload). Discussing how to position navigational displays for ease of interpretation during the flight		
06:10	*Pre-flight Checklists:*	'Gosh, these PFDs are annoying, aren't they. Down on the bottom right there.' 'Ye. They are an awful.'		'Now what I'm doing there is having a look at the overhead panel there just double checking making sure all the switch position are in the correct positions for the take-off there.' 'We would have normally checked that in the other checklist leading us up to the runway there, but because we are in the sim I just did quick check there.' 'I'm looking for mainly that all the switch positions are in auto, because of the most of the systems on the J are automated. Checking to see that the fuel set up is correct. That's an important one. Making sure that the correct tanks are feeding into correct engines & there no cross-feed set up, sufficient fuel is in each other tanks, which you would have obviously checked before you have been started. And also from my line-up checks that was another of the main things turn of the PITOT heaters & the NESA heat, which is the windscreen heat and that the strobes are flashing white, which is all part of the line-up checklist.' 'I will give you a little background info there. The Primary Flight Display there as you can see with the yoke, the top the yoke lies right over the radio magnetic indicator (RMI). When the yoke is fully forward as it is prior to the take-off there. It's very hard to check the selections you've got in pointer 1 & the pointer 2 & also once you take off you looking for the distance the radar then has the at the bottom there. It tells you how far away from the runway you are, so it gives you an idea of when to turn. And also even during flight, when the yoke is a little bit further back, it still does cuts of the bottom of the RMI there. So you can't read RMI, which is the just the compass card there, which just			M	Checking overhead	Overhead console	PFD – data needed. Pilot's are looking for/calculating the point of turning from the distance away from the runway of TO presented by a radar on PFD. PRINCIPLE – pilot need a reference system to always maintain the SA & to tie the information some where – need for continuation on info in anyone's mind in order to retain the information.

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				underneath the attitude indicator there. So it makes a little bit more difficult, increases your workload to check behind the column there, to read there everything you need.' 'With HUD it's is perfectly displayed, it's right in front of you, but the PFD you don't have any more analogue instrumentation to tell you. So you really have to rely on your PFD once you've lost your HUD. On the NAV/RADAR display it's perfectly displayed.'						
07:20				'I was checking in the REF/Mode panel the MINIMUMS, which is the height that we have for the Instrument Landing System into Sydney, and also the Radar altimeter height that we have. On the approach plate you will see 2 heights, one is the barometric setting & the other is the RADAR alt setting. I was just checking those sort of selection & to see that the figures where correct, because the aircraft will tell you once you get to MINIMUMS. You will hear on finals it will go 'MINIMUMS'. It will tell you, that you are at MINIMa. Obviously that's a check for us if you are not visual you have to go around, but if you are visual obviously just acknowledge it & continue.'			M	Checking speed reference panel		Need to see 2 heights, again the REFERENCE system principle. MINIMUMS – points of reference for pilots
07:31				'And I'm just checking of my instrument approach plate there the figure that I just checked in the REF/Mode panel'			M	Checking T/O chart???	???	
10:40				'There is nothing on the mode selector panel at the moment. You will see me selecting 'SEL' button on the mode selector panel, because that's a minimum selection we do prior take-off.' 'I'm selecting 'SEL', so that when we are in the climb out there, the FD will give me the information to intercept the ALT we've got set in the ALT/SEL there.'	Final adjustments		A	Arming mode ALT/SEL	REF/MODE Select Panel	Information selected on first on the Ref Set part of the panel & then pressed as a mode on Mode Select Panel, the result of which appears on the PFD – 3 places!!!
10:56				'Checking the stand-by Attitude Indicator. If we loose electrics we've got to have a reference to the Attitude out there, so it's really good.' 'I'm setting the barometer there. I've looked into the top of the take-off data, have got what QNH that was supposed to be set. I set that on the stand by & then went into the REF/MODE panel & set it there. What I'm looking for appear in cyan at the bottom right hand side just underneath the altimeter (on the PFD) '			A	Adjusting Standby Altimeter	Main Instrument Panel	

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11:02				Same as above				Adjusting the QNH on the REF/MODE to appear on PFD	REF/MODE Select Panel	
13:07				'He is just marking around there.'				Doing something on AMU	AMU	
13:30				We just selected a mode on a radar, we are just going to get an ACOS (Aerodrome forecast) in a second			AP	Listening ATIS	AMU	
13:50				'It's a sim problem. I stored an ACOS there. I normally not store an ACOS like that in the aircraft.'				Inputting radar information	AMU	
14:21	~**ATC clearance:*	'Glendfield 1 departure, climb maintain 3000. Clear for T/O'		'My consideration at that moment is to insure that. I'm not looking at PFD at all not. Runway is clear, that's why I'm looking out there. We just got a clearance for take-off. Making sure that... I'm going to take-off park break in a second. That the throttles are all aligned correctly that they are all in the high-speed ground idle. That we've got all the line-up checks complete & once I've done that & I'll just be worried about looking at the runway there. Making sure I'm straight. I'll take a couple of glances in at the airspeed & that's all I'm looking for to get our rotate speed.' 'Turning the landing lights ON, which is another procedure for the co-pilot to do once we've got the take-off clearance.'	Coordination with other traffic	ATC-Crew	A	Indicate cleared route	Radio	'throttles are all aligned correctly' PRINCIPLE – actions projected into the future (for example they will veer to the right if they don't align all the throttles). 'in the high-speed ground idle' – that's also is not shown anywhere apart from the throttle consol. Same PRINCIPLE – project it into an effect they will have, ie as if pilots visualise it
14:29	*ATC clearance:**				Coordination with other traffic	Crew-ATC	A	Read back to ATC clearance	Radio	
14:35	TAKE OFF	'Copy clear for T/O. Glenfield 1 departure 3000. *3000 Set.* Set & checked. Crew rolling for 102 knots''		'Crew rolling for 102 knots.' is the speed I'm looking for, that's our rotate speed & the refusal speed.'	Crew cross-reference (same model/picture)	PF-PNF-PF		Saying T/O runway, airport, clearance altitude, ref speeds	Intercom	
	AFTER TAKE-OFF			'Quick glance at the speed.'				Rolling down the runway	Throttle	

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14:56		'My controls. Your controls.'						Passover of controls		
TIME LINE:	**SEQUIENCE OF EVENTS:**	**DIALOG:**			**GOALS:**	**FROM -TO**		**ACTION/ MONITORING/ PLANNING:**	**OBJECT S USED:**	
15:03		'Rotate'						Rotation	PFD	
15:10		'Landing gear up'		'The balk of my concentration is gone down to the attitude indicator on the PFD & I'm looking at the flight path marker relative to pitch ladder. And to see what my wings are level. And I'm also dropping my scan down to have a look at the RMI & where heading bug is, so that I know I'm flying the correct heading, we require for the departure.'		PF-PNF		Commanding Gear up	Main Instrumen t panel: Landing Gear/ Landing Light Panel	'I'm looking at the flight path marker relative to pitch ladder' – PRINCIPLE – pilot's reference system/comparisons within the display 'also dropping my eye to the RMI to see where is my heading bug' – need to be ahead since flying towards it – up
15:18		'*Track 095 at 1 TAC 1000ft, which ever is required. Turn right.* Turn 095.'			Crew cross-reference (same model/pictur e)	PNF-PF		Verification of the turn after T/O		
15:27		'*Landing gear is up.'*			Crew cross-reference (same model/pictur e)	PNF-PF				
15:28		'Flaps up'		'The other thing I'm looking at there is for before I call, 'Flaps Up', that we have sufficient airspeed. So when I suck the flaps up, I'm not going to stall or anything like that, so other part of my scan is across there to the airspeed is to make sure that the airspeed is healthy & increasing'		PF-PNF		Command flaps up	On Center console: Wing Flaps Control Quadrant Panel: Flaps lever	

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15:33				'I'm about to reach out for the heading bug on the Mode select panel, so that I have the horizontal mode of the FD come up & give me information on keeping the heading bug rather then looking at the tiny little tick mark & the heading bug marker, I get a nice big line in front of me on the attitude indicator. And all I have to do is put the circle in the climb dive marker or flight path marker over the top of that dot And make sure that I'm tracking my heading.' 'Just trimming back to. Usually when you roll your elevated trim is about level, once you start taking off & you are in the climb you need to trim back on that, because it just takes the force out of pulling back on the yoke.' 'You just see on the top left hand side of the PFD the heading selection came up there. You can see the FD there.' 'The Altitude is selected & the Heading' (modes announced on the PFD)	Offloading work automation (*didn't tell to PNF)*	PF-Autom		Switching heading mode on	Ref Set/Mode Select Panel: HDG mode button	'' – pilot gives an example of information merging on the PFD
15:46	'*1000ft*. 1000. Just waiting for 1TAC. *Roger*.'			'You can see there… the 2 needles pointers I'm looking for the distance on the bottom of that & it's very difficult to see.' 'Ye, I know I'm on course, because the FD is helping me there. All I'm worried about now is the distance. We've already made out our hard requirement for the departure, we are just waiting for that distance to come up before I can make right turn.'	Crew cross-reference (same model/picture)	PNF-PF-PNF	MP		PFD	Pilot's REFERENCE system – 'waiting for the right distance to come up before we can make our right turn'
15:55	*After take-off checklist:*	'After take-off check. *Landing gear is up.* After take-off checklist complete.'				PF-PNF		Commanding execution of after T/O checklist		
16:01		*'1TAC right turning, track 170*. Roger. Autopilot is engaged & turning around. Right turn 170.'				PNF-PF		Turning right after TACAN	Display? (PFD or NAV)	
		'Autopilot is engaged'		'I just engaged the autopilot then. Once I was happy with the FD indication. It was centred in the FPM, I engaged the AP make sure that the AP doesn't all over sudden do an abrupt turn to try & intercept the FD. Once I've done that the AP was coupled up to the heading mode on the mode selector panel. That way I can just use the heading knob. Select it onto 170 & the aircraft will just fly itself around on the 170.'	Off loading workload to automation	PF-Autom-PNF		Engaged the AP through the yoke	Mode annunciation panel	

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				'See it's flying itself now.'						
16:13		'THOUSAND TO GO'		'You just heard 'THOUSAND TO GO' voice came through. It was obviously telling how far to go before we reach our height there, which we select in ALT SEL & part of our checklist procedure is to check that verbally with other pilot, so that they are also checking what's in there own, we know that we are not going to keep going straight up through that height.'	Sharing information	Autom-Crew			Voice	'we know that we are not going to keep going straight through that height' – need to see if they are going to level off or not. REFERENCE – current vs. level off height
16:17		'Approaching 3000. *Checked*'		'No, I'm quite happy there. The mode selection I've got select that heading of the aircraft to fly itself there. I'm also not worried about the height because I know that I've already hit the ALT SEL button so AP is going to capture that & it's aircraft going to level off us at our height. I'm just monitoring now. I can step back & watch the aircraft fly. If it does something that I don't want it to do. Then I will take out the automation & get it back on track & then reselect.'	Crew cross-reference (same model/picture)	PF-PNF		Climbing to ALT	PFD	
16:20	~**ATC clearance:*	'Contact Sydney approach. 135.9' '135.9 Treasure, 123'				ATC-Crew		ATC contact		
16:33	*ATC clearance:**	*'Sydney Approach, good day, Treasure 123 is in the right turn passing 2.900 climbing 3000.'* 'Good morning, Treasure 123, continue climbing via Glenfield 1, excepting vectors runway 007 ILS'. 'Glenfield 1, understood. Treasure 123.'		'See my workload is gone right down now.'	Change ATC			Change of ATC		
16:51		'For some reason my INAV posses, staffing up'		'See light came up on the mode selector panel there. That comes up to say that it's ALT HOLD. The FD does that it's itself.' 'I can see red marker in the centre of the course. The course Annunciator came up to say that it's not working. & so now		PF		Verification of ATIS		Pay attention to the PFD top left changes from ?something? under the line to the top of the line - ALT

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				what I would have been relying on there is the course indicator bar would tell me how far away I'm from the INAV track. It's not doing that. So now I have got to scan that little needle & make sure it comes around on the correct *(It's on the top of where you heading right now*) Now I'm watching the pointer 1 & that's the whole reason I set up the Glenfield NDB before we departed. In case it failed I now had an indicator to tell me that it was pointing directly at Glenfield, but my workload is increased now, because now I got to make sure that I intercept the correct radial. Rather than have an indicator bar, which is a lot easier to follow, I just fly until it goes through the center, then it's done & the AP can do that for me. But now I have to do via that needle, I have to do it manually. So I've got to go back to the heading knob to turn on to the correct heading to intercept that manually. FD is not helping me, it might as well not be there.'						HOLD, VS arrow goes down right away & ONLY a second later does the ALT HOLD button lights up on the mode selector panel. Same information in 3 different places
17:08	NEW LEVEL FLIGHT clearance	'For 5000 thousand'. *'5000 left 3000, Treasure 123.'* 'Copy 5000'. '*5000 set'. '* & checked. Leaving for 3 for 5.'		'See ALT HOLD selection just dropped out there, because we left our height. And all I did was just put the power up high for our climb.' 'See the FD## is gone back to horizontal (*may be vertical?).* All it's doing it's giving me heading information.				ATC new ATL clearance	ALT button on the Mode Select panel dissappeared	Pay attention to the PFD top left changes from ?something? over the line to under the line - ALT HOLD, VS arrow goes up right away & simultaneously does the ALT HOLD button lights switches off on the mode selector panel. The change from top to bottom & vs. happens in less then a second, so as the automatic switch off the button happens at the same time of a change, i.e., there are no clues left that the change has occurred. Same information changes in 3 different

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										places. It should be all happening on ONE place, ex. VS tape/arrow TD – see on my TV FD change## At the time of the ALT HOLD change FD cue on PFD changes to FD 'Azimuth-Onside cue'
17:36		'Coming around to our course'		'FD is not doing anything for me apart from keeping me on heading. But what I'm doing, which (FD heading) I just selected. I had to manually think of: 'I'm coming around to this radial, there is 2 degrees lead on the NDB now, because we are about 20 miles away from it, therefore if I'm turn now, I'm gonna roll out on the heading inbound to the Glenfield NDB of 144. That's the calculation I'm doing mentally. And all I'm doing is manipulating the heading bug to give me what I want from that needle, but the FD is not helping me.'' *Where did you acquire the distance that you just calculated?* I didn't (acquire that information). I knew, because I looked on the chart before we left. It's about 25 miles is the profile between the Glenfield NDB & Richmond. And I know we hadn't been flying for more then 2 or 3 minutes at that stage so we gain 5 miles or 10 miles may be, so we still had 15 to 20 track miles to the NDB to go & that's just a piloting skill. That's what you keep in the back of your mind I guess. That's what good about NAV/RADAR display because of the range ring on it as well.	*Crew cross-reference			Crew cross-reference of the course		'*I didn't (acquire that information). I knew because I looked at the chart before we left*' – The pilot had to retain the distance in his head, estimate the amount of distance that they already passed, deduct & receive current distance away from target.
17:48		ATIS info 'Sydney Terminal information Alfa, Runway 07, wind 120 degree 15 knots, clouds scattered 1500, overcast 3500, visibility… QNH 1022, temperature 15,			Acquiring only externally available information		im u	Request on a new ATIS from ATC		Pilot have to retain information in memory ex.ATIS to proceed in there 'forward' thinking, memorising numbers, turns, height…etc

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		expect ILS.'								
TIME LINE:	**SEQUIENCE OF EVENTS:**	**DIALOG:**			**GOALS:**	**FROM -TO**		**ACTION/ MONITORING/ PLANNING:**	**OBJECTS USED:**	
17:51		'THOUSAND TO GO'			Sharing information	Auto m-Crew	lt		Voice	
17.53		'Approaching 5000.' '*Roger*'					ani ous			
18:25						Auto m-Crew		Sounding a message on the display	EFIS? center	
18:30					Offloading workload to automation (ATHR)			Engaging a new ATHR mode	Ref mode set panel, pushing 'A/T ON' button & setting the value on the left IAS value of 170 knots	The ALT ON button on the Mode Selector went on as well, although PF didn't push it.?????
18:31		'Autothrottle set for 170.'		'I just hit the ATHR mode button there on the Mode Select Panel Takes one more thing out of my scan there, not having to worry about the pushing & pulling on the THRs. In the rotary selector knob I just set the speed that I want to fly. The only thing (announced) you get on the PFD is on the acceleration caret, which is just beside the FPM. There is not actual reading on the PFD. The only way you will know that the ATHR is engaged is that little caret on the side there has a diamond in it; it puts a diamond on the back of it.'		PF-PNF		Change of airspeed through	Ref mode set panel	
18:40		"All right mate, can you just brief us through the ILS."		'A quick glance across to the NAV/RADAR there. Just thinking, OK, pretty much know where I'm now.'		PF-PNF		PF 'glanced' about 3-4 times, then PF asking PNF to brief ILS approach from the plate. Both change their	On the steering column	

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								paper approach plate.		
18:49		'Point for the ILS, etc.' *'5000 set for localizer; for 3000, finals course is 062 Outermarker check height 1300ft; Decision height is 270, to set in the mins 254 & the radar ALT is & the missed approach is at the decision height, we will brief that if we need it; & the ?edge roll? On Sydney.* Understood			ILS brief - Crew cross-reference	PNF-PF		Reviewing Points		
19:05				'I'm just checking what he is telling me, of the information of the sheet, making sure it's correct. I was checking the information that the PNF was reading to me in the approach plate. What we are doing at the moment, is briefing the approach that we are going to fly into Sydney. Switch the knob & have a look that the correct value is set in there. I was looking at the RAD ALT & the MINIMUs.' 'There is a little rotary selector knob, there. I was just changing it round to the position. See that's the only display that RADAR, what ever I select it will come up with a, like if select FPA it would change from 170 knots which I've got in the ATHR to -3.0.'	checking correct information	PF		Changing/Checking data as PNF briefing the ILS	Ref mode set panel	
19:15		'Treasure 123 report indicated airspeed.' '*170*'. 'Treasure 123 copy that for sequencing increase speed to 210 knots.' '*210 Treasure 123'*				ATC-Crew	si	ATC requests airspeed increase Crew change the airspeed	on the Ref/Mode panel	
19:20				'What I was doing over in the Avionics Management Unit there was setting up my finals course for the ILS. When he			l	Touching	AMU	

TIME LINE	SEQUIENCE OF EVENTS:	DIALOG	UNDERLYING PILOT'S REFERENCE SYSTEMS	COMMENTS - DEBRIEF	GOALS:	FROM -TO		ACTION/ MONITORING/ PLANNING:	OBJECT S USED:	NOTES
				told me the speed there, I was still marking around with the course knob, setting the course up. I was trying to look over the edge of a wheel there to see what the course was set up.'						
19:33		'Copy 210'		'It's 210. I change the speed selection for the ATHR to 210.' 'To see that everything is tracking correctly (on PFD). I was mainly looking at the compass to set up the course. That gives me my course indicator bar & the next thing I was looking at once I've made that speed change to 210, I was looking for that the speed tape was increasing.'			ta	PF changing of airspeed through … on ATC request due to other traffic	Ref mode set panel	'*looking for that the speed tape was increasing.'* PRINCIPLE Show TRENDS of change once manipulation was done to the system or in an usual trend change
19:15-19:40				'The Morse code was coming through there. I was pulling the selector button on the side to listen to see that the identification against the Nav aids we were going to check, coming into Sydney was the correct indent, because if you tune the wrong frequency, you are not going to be tracking the right Instrument Landing System down, because they've got several. That's the only way to check it.'	Crew cross-reference		mu	Verifying Nav aids		
19:56		'We won't worry about the approach checklist, we haven't really left the landing patter, so.'				PF-PNF		Amending the approach check list		
20:04						PF		Touching? Or checking?	?AMU?	
20:13		'… duty Runway now 16R… (plus new weather), …		'I'm going, "GREAT"! Now we have to change everything we've just preset.'		ATC broad cast		ATC change of runway		
20:25						Auto m-Crew		Sounding a message on the display	EFIS? center	
20:26		'Turn left further 25 degrees, expecting radar vectors shortly.'		'What I'm looking at there, now, that the co-pilot got instructed by ATC to turn left 25 degree. I'm just having a look at what heading we are there, taking 25 degrees of that & turning the heading bug to there. That's all I'm worried about there.'		ATC-Crew				
20:33		'Left 25 degree, 123 inside… the wind for						Crew request ATC winds for		

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		the new information Bravo						new runways		
20:45		'Left heading 123'			Following ATC instructions			Turning left		
21:04		'16 Right; Finals course is now on 55 starting from 5000, back to us on to finals; decision height is now 220 at set of min for RadALT is 212; outermarker check height is 12,7 DME 1295… '		'That's not how we normally operate. We would always have our operation plate with us. Procedurally that's bad, we have to have plates in front of each pilot. Now I'm relying on what he says to be 100% correct that he hasn't misread the plate & he told me the finals course was 155, & it was 157. & then all over sudden I'm tracking the wrong ILS or something like that or listening to the tower. Now, that sort if thing is going through my head. I'm going great. The runway has changed. We don't have any plates here. We only have one plate between us. Now it's going to get fun.' 'You can see the CDI moving around there. PNF is quickly briefing different requirement there heading & stuff. I'm just setting it up.'	* Crew cross-reference for approach			PNF Reading an approach plate		
21:17				'I'm checking again the RADALT & the MINS that he just read me are correct & that he is setting the right ones. See when he I went there (Ref mode panel). I was not actually changing anything, he was, but I can watch him change it. If I have started to move the knob, it would have been conflicting with what he was doing, depending who gets in first is what happens to the figure. So that's a pre-coordination issue.'	Checking correct information	PF		Checking data as PNF briefing the ILS	Ref mode set panel	
21:34		'Continue left turning 090; intercept 2 mile arc; intercept 1NM for the 16R ILS'				ATC-Crew				
21:52		'Copy left heading 090 to intercept the… 2 mile arc'		'Now, what I'm looking at here is I'm going: 'How am I going to intercept 12 mile arc, when I don't have the VOR needle up', because we have selected the ILS frequencies in there. You saw me glancing across the NAV radar display there. I've already had a look at the range rings there, when we got that radar vectored heading, we were already inside 12 miles, which meant that's not the way the ATC would normally vector us. That's why we had to turn all the way back up to the North there, to go back out to 12 miles. You	Crew cross-reference	PF-PNF		Selecting appropriate Tuning Nav aids (VOR;TACAN)	AMU	Information missing on the display – VOR needle Interesting reference =) – 'to back UP, NORTH' North is always UP on all maps – common view. Reasoning/reference

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				take a radius from there. You know he (ATC) gave us vector for about 9 miles. So we were already out of time there for the arc itself, so realistically the ATC shouldn't have given us that, but obviously that's the limitation of the guy running the sim as well as the ATC. So that increases our workload even more, because now I've got to think about getting us back on track before we can start the approach. So I'm looking at distance & then I'm thinking at what distance do I want to turn to incept the arc to get back on profile again to where I can intercept finals.' (Iya) '… & all of that you are thinking in your head?' 'Yes, the FD can't help me, because the ILS is selected up there at the moment.' (Iya) '… you can't change that?' 'We could change that, but it would be more work for us to seat down or look into the CNI quickly change the VOR needles & then by the time… The other thing I was thinking, we are very close to the finals course, but the time we select the VOR needles up, I will be on my 12 mile arc & then all over sudden we've got to select the ILS frequency again anyway. So that the CDI bar is going to give me information on the intercepting the finals course. So it wasn't worthwhile changing over for that long, it would have increased our workload more. So what I'm looking at is the distance on the bottom of the PFD there & working out at what distance I have to turn into the 12 mile arc.' 'The FD is taking the some workload of me right now, because the AP is coupled up. It holding me my height, it's flying what heading I wanted to fly, it's flying what airspeed I wanted to fly. I don't have to worry about that. All I have to worry about right now is how are we going to get into ILS.'						systems '…because the ILS is selected up there…' Automation use is avoided sometimes because it's creating workload. '… **working out'** performing calculation
22:13				'I'm just looking here, & thinking, this does not work out. We are way close to the airfield & they've told us to intercept what we've already through the 12 mile arc, so what I'm going to suggest to PNF is ask the ATC, we are suppose to intercepting the 12 mile arc, & then it prompts him to say: 'sorry about that' & then he will give ridiculous heading to turn around on to it now.'	Crew cross-reference	PF-PNF-PF		Verifying Nav aids		

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22:54		'We need to be… ILS course 155; we are inside it now. Yes.'			Crew cross-reference for approach*		im	Discussing aircraft position in relation to ILS		
22:53							ul	Verifying Nav aids		
23:01		'*Approach Treasure 123 request further left heading to intercept 12 mile arc.*'				PNF-ATC	ta	Asking permission ATC to make left heading		
23:05					Communicating with ATC	ATC-Crew	n	ATC confirmation of the route		
23:18		'Left heading 360. Copy that.'		'What he has done is given us the heading to intercept & by rights we have to fly that heading that he has given us, until we intercept that arc, but we already been given that heading once we are inside that arc. So technically I can't turn until he give us another vector to get us back out. If I just start tuning in the direction I want, that's dangerous. That's stuffing the ATC sequencing. That's why I got PNF to query. Then he (ATC) says turn left immediately, back up to the North.'	Crew cross-reference	PF-PNF	us			
23:36		'Continue turning heading 315 to intercept.'		'Again just checking that ILS frequency is correct & checking the Morse code ident for that.'		ATC-Crew				
23:43		'315.'			Crew cross-reference	PF-PNF			Forgot to replay to ATC!!!	
23:45		'360 for us…'		'What happened there was, the ATC gave us a heading to turn on to I heard it select it around, but the PNF thought it was for another guy. And you watch the ATC will go back to us & tell us turn left on heading 315, because that was what we suppose to turn on to.'	Crew cross-reference	PNF-PF				
23:51		'Continue turning heading 315 for intercept.'			Making sure that the crew is following instructions …	ATC-Crew				
23:54		'315. Apologies'				PNF-ATC				

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23:59		'That would be 315. Selected'			Crew cross-reference	PF-PNF				
24:06		They still have got us at the speed restriction at 210, are they? I haven't heard otherwise'		'I'm queering the speed, because to organise myself to intercept that I don't want to be going 210 knots, 90 degrees to that finals course. The higher your speed, the larger is your turning radius & the more you are going to blow through to have to come back & to intercept there. So what I wanted to do is to slow the speed down, so it was more standard & smaller turn radius. Much more easier to intercept the ILS finals, because I knew we were getting close to it. Then I eventually made a decision to wind it back myself. It's probably. It's not standard, I shouldn't have done that, but I would have hoped that the ATC would understand that, because we have to start configuring the turn on it & they cleared us for the approach. We are the only ones that were in it. That's why I did it. '		PF-PNF		Discussing the speed restriction		Pilot's need to REFERENCE old information to new to keep a continuum & in RELATION to surrounding (finals course vs. turning radius, height)
24:25		'At 10.5 we make a… right turn to intercept the arc dark raw. Roger'		'So all the FD is doing there is giving me the heading to fly; holding the ALT. That's it. All I'm watching for there down the bottom is the distance to come up for me to turn to the arc. That's the first turn.'	Crew cross-reference	PF-PNF		Planning position of right turn		
24:37		'Descent to 3000. You are number 3 in the pattern'				ATC-Crew		ATC position in the queue & change of ALT		
24:41		'3000 from 5000.'				PNF-ATC				
24:43	DESCENT	Copy 3000 leave 5'				PF-PNF		Start descending (automation)		
24:45		'3000 set. Checked'		'The ALT HOLD just dropped out & that's why we just lost that forth light. He was reselecting it reselecting in the ALTsel. So that's what the co-pilot is doing. I'm watching at the top of Altimeter tape there that the cyan number is going down to 3000. That way I know once I roll over the control wheel & the aircraft is established on descent, the FD is going to capture my next altitude. That's another thing I don't have to worry about.'	Crew cross-reference	PNF-PF		PNF setting new height. The mode disengaged from REF/MODE panel the ALT ON button went off & changes on PFD from top right ALT HOLD to bottom right	Ref set mode panel	Infor the pilot is looking for.

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								ALT…?. And of PFD the FD vertical bar appeared.		
24:56		It's 9 mile.								
24:57		Roger, I'm going to bring that speed back		'I just wind the speed back' (without ATC command)		PF-PNF		Slowing aircraft down, through changing the ref speed	Ref set mode panel	
25:12		'And I'm going to make a right turn.'						Making a right turn		
25:19		'THOUSAND TO GO'			Sharing information	Auto m-Crew			Voice	
25:23		'Approaching 3000. Good'		'Just when we move the heading bug there, 90 degrees to it is where the CDI bar is. Again we didn't have the VOR. I couldn't tell what radial we were on, I couldn't tell what lead radial we were going to require before could turn on to the course. I guess to replace, so I what I did just to turn 90 degrees on to it to intercept that track across to it.'						REFERENCE – '90 degrees to it (HDG bug)' 'I couldn't tell' – info missing without programming certain parameters. Shouldn't be possible to estimate that on the display itself??? Take that into account in the design.
25:39	APPROACH	'You are cleared for Sydney ILS 16R for the 12 mile arc. Once established on final contact tower 120.5. Good day'				ATC-Crew		ATC clearance for ILS	Approach ARM mode	
25:49		'Cleared for ILS 16R. Once established on 120.5.'				PNF-ATC		The vertical blue bar went away on PFD & the ALT HOLD appeared again on the top right of the PFD????		????

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25:54		'Copy cleared for the ILS'				PF-PNF				
25:57		'& going APPR arm'		'What I just did there, standard procedure. Whenever we get cleared for the ILS, not just cleared for finals, I can fly the glide slope as far as I pushed in the approach button on Mode selector panel & what that does is arms the FD to tell me my azimuth course deviation & it also will capture the GS once it's outside the comes down the meters. So the AP will capture that & begin to fly me down the GS. Heading is still controlling the direction of the aircraft, but now that I've select the APPR ARM & what that will do is the FD through the AP would turn the aircraft on to finals course.'		PF-Auto m-PNF		Pushes APPR ON button & on Mode Announc. Panel 2 light come on, NAV ARM & GS ARM & 2 new mode annunciation comes on top of the PFD The ALT ON button on REF/MODE panel went on last as well ones they captured the ALT	Ref set mode panel	Too many annunciations at once for 'one goal' information
26:02		'& we will go ahead with landing checklist.'				PF-PNF		Landing checklist by PNF		
26:04		'Flaps'				PNF				
26:06		'Below 183, flaps 50'								
26:15		'Flaps are 50'			Verification	PNF-PF		Flaps setting 50	Flap lever	
26:17						PF		Reaching for ??? Speed mode changing speed for lower	Ref set mode panel	
26:25		'Landing gear'				PNF-PF				
26:28		'& landing gear down'		'I will just explain to you what I'm doing there, We are just about here; we are almost ready to intercept the finals course there. I'm configuring the aircraft ready to go down the slope. So what I did there is called for the landing checklist. Looked at my speed, because I've already bugged it at 170. I knew we were below the flap setting speed we require, so we got	Verification	PF-PNF		Landing gear down		

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				straight into the checklist. He drops the flaps, so the next thing I do, once he drops the flaps, wind the speed back to 150, which is now brings us below our gear limiting speed. So when he gets to the landing gear part selection of the checklist the speed is below it & we can drop the gear. And we configuring to fly the approach. I'm again winding the speed down. All I'm doing is manipulating the ATHR there. I'm just taking from 170 back to 150.'						
26:45		'Landing gear down, three greens'				PNF-PF				
26:47		'Down, three greens'		'My head movement there was just looking at three green lights, on the gear panel & make sure it is down, indicating down & check that the nose wheel is centred.'		PF-PNF		PF looks to check is three light are green		Same as above – PROJECTIONS PRINCIPLE as of current state 'Can't land, because not landing gear' for example.
26:49								Landing checklist complete		
27:10		'I've got … on my side. Appears to be capturing'		'You could see over on the Mode Annunciator panel we had a shift of that lights. It went on from NAV ARM to NAV CAPT, which means that on the horizontal mode it just captured that azimuth, so the aircraft will go: 'Oh, we've got it. Let's make a right turn.' & will intercept the azimuth for the ILS.' '& you also saw that the HDG selector went on the mode selector panel the light went out, because now the NAV mode that's controlling not the HDG. I changed it, I wind it down, but it wasn't controlling the direction of the aircraft that time.' 'You can see at top the Attitude indicator I'm looking for the other cross to NAV CAPTure. It's a double check of the aircrafts, captured the NAV solution. That's a double check.'		PF-PNF		Capturing ILS HDG ON button went of on REF/MODE panel & NAV ARM switched to NAV CAPT on Mode ann.panel. On PFD the left top bottom mode annunciation went to the top.	lights change on the Ref set mode panel & Mode Announci ation panel…?? Which mode change? $$$There is a delay in pilots respond for about 3 sec… possibly	

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									because the indication is just a light???	
27:44				'What it is doing there, it switched to NAV ARM again (*I'm not so sure! The change is from GS ARM to GS CAPT & REF/MODE panel the ALT ON light went off*), because we are flying through it, because there was a 90 degree intercept. It was too rough for it, so it's gone through it & it's gone out. Now, it's going, 'OK, I'm established on a turn, now I'm going to come back the other way. ' That's why it's pointing that way, it's doing another interception of the nav course. You can see that, there. It's just gone through it, but if we were doing 210 knots, that would have been way out.'		Auto m-Crew			Light's change again on the Ref set mode panel & Mode Announci ation panel…?? Which mode change? $$$ 10 seconds delay in pilots respond	
27:54	ILS captured	'& we have NAV capture there'				PF-PNF		Rotating knob on		
28:05		'Established ILS finals 9 miles 3 greens'				PNF-ATC		ATC change new frequency, contacting Sydney ATC	AMU	
28:12						ATC-Crew		reading back		
28:23		'Left 3000 for minima 220'		'I was looking at the NAV RADAR display, but I don't know why. I think I was just checking the general orientation to see that all is matched up.' 'What I'm looking at the PFD, that the CDI bar is central, the GS indicator is down the left hand side of the attitude indicator is right on the centre dot & then I'm looking at that the flight path marker is right around the FD there, which is giving me azimuth & GS information. Just monitoring that is				Checking	Ref set mode panel	

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				all I'm doing there.'						
28:34		Outermarker check 4.7 DME, 1295'			Crew cross-reference	PNF-PF				
28:43		'the beacon button pulled. Roger'		'All I'm doing is focusing of the PFD. It's very important to do that in the approach.'		PF-PNF				
29:00		'Land in view. Right.'		'The Co-pilot is giving me cue from outside. He is just telling me what he just seen out there, because I'm focusing on the PFD, because I'm the PF at the time & then once he said 'Visual', then I can look up from that & I can make the assesment the runway, the visibility, the distance that we have & check if that is what is required for the approach.'		PNF-PF				
29:26				'I did a glance to the right there, the camera probably didn't show, but I was looking at the CNI there, to make sure that I had the landing speed page up in the landing data, so then I could check my approach threshold speeds.'		PF		Looking at CNI	Landing page data	
29:47						PF		Referencing outside	Runway	
29:47		'Runway visual. Got Runway in view also. Continue down for the glideslop there. Roger.'				PNF-PF-PNF		Visual of the runway verification		
29:54		'Good for 1295'		'You can hear the beacon coming through. When I said before my beacon button is pulled, what that allows me to do at the outer marker, which is that sound. All it is just a radio beacon underneath & that particular point, at that distance from the runway that give us an accurate check at 1295 feet. That we are right on glideslope. It validates the landing instrument system for us. & by us checking we know that the GS is good & it checks out & then I look at the PFD then & make sure the GS indicator is right on the center.'	Height & slope check	PNF		Listening to beacon aids - passing over	External sound – outer marker	Again – REFERENCE – PROJECTION with the current where will you be.
30:05		'The height is checked. & that's good to go.'				PNF-PF				
30:09		'Outermaker 3 greens'				PNF-ATC				
30:13					ATC clearance to land	ATC-Crew		Confirmation		

TIME LINE	SEQUENCE OF EVENTS:	DIALOG	UNDERLYING PILOT'S REFERENCE SYSTEMS	COMMENTS - DEBRIEF	GOALS:	FROM -TO		ACTION/ MONITORING/ PLANNING:	OBJECT S USED:	NOTES
					(confirming – 'same picture')					
30:15		'3 greens'				PNF-ATC		Checking landing gear		
30:19	LANDING	'Copy clear to land. Speed is coming back. 136; 126 at this stage'		'I've gone through outer marker there, that's my cue to start slowing the aircraft now to the approach speed. So you saw me winding the airspeed there. I previously looked at what speed I was aiming for at the CNI & I was just coming back to that speed.' 'Now what I'm trying to do is to establish the frame of reference within that window, where the runway is, what my instruments are telling me, so that I can... if you've been starring inside & when they finally look outside & that's when you got to flare & land, it doesn't give you enough time to adjust to a new visual environment. So I'm trying to establish the visual environment again & get my eye in for where I'm aiming on the runway. The last think I'm thinking about here, when I'm going to take off the automation. & I will use the FD to give me the information to give the GS information down to the runway, because it's usually more accurate then to what my eye can tell. So I will use that to help to get my aim point & I will also waiting for my speed to come back to select the 100 flaps, which is the normal landing configuration.'		PF-PNF		Reducing speed through	Ref set mode panel	Pilots seem to always have a reference in time, space on instrument to reference to for he next move/manoeuvre. So IDEA is to give them that REFERNCE easily available.
30:51		'And disengaging, disconnecting manually. Below 145 (speed) that's 100…'		(*There is something flashing on the top left corner of the PFD*) 'That's the function of the AP. By me disconnecting the AP on the control wheel. It will flash for a little while & tell you that the AP is off. I think it's 7 seconds or something.' 'When you heard me say (*see left*)…. I was disengaging the AP & disconnecting the ATHR. & that's when I said I'm fly manually.'				Disconnecting manually AP	On the control column	
								Looking outside most of the time		
31:01		'Flaps are 100'				PNF-PF		PNF selected flap 100	flap lever to 100	
31:04		'& speed checks'				PF-PNF		Looked at center panel	(flaps check?	

TIME LINE	SEQUENCE OF EVENTS:	DIALOG	UNDERLYING PILOT'S REFERENCE SYSTEMS	COMMENTS - DEBRIEF	GOALS:	FROM -TO		ACTION/ MONITORING/ PLANNING:	OBJECTS USED:	NOTES
									landing gear down, engines?)	
31:14								Looked engine indication		
31:19				'Just glancing on the PFD there, just to make sure that everything is still right. Can see that I'm relatively on GS, just a little bit above, actually just a little below, because it's fly to.'				Looking outside most of the time		
31:29		'MINIMUMS, MINUMUMS'			Sharing information	Auto m-Crew			Automate d reminder	
31:31		'Acknowledged, visual. Roger'		'That's why we set the MINS there. It's telling me I'm at the bottom of the approach there, make a decision to land. All the requirement are met, the have the required visibility. That's all we need.'		PF-PNF		Crew acknowledged the voice reminder		
								Looking outside only		
31:56	TOUCHDOW N	'Your controls. My controls'		'It's all is visual now. Once you've got over that runway you don't need to bother looking inside anymore, because the last thing I looked at when I was over the threshold was my threshold speed, once I knew I was at that I could afford to pull the throttles back to flight idle & know that my speed would decay down to my touched down speed. That's the reason we have those speeds. The rest of it is centreline & obviously I was a little bit all over the place there. That comes from familiarity with the flying heads down, that's different, with the HUD You have got a big climb-dive marker there right in front of you & you can align it right up with the centreline. Makes is a lot easier. '				Landed		

~ event can occur any time
event - it indicates start & finish of the task
Dialog of Pilot Flying (PF) – straight text
Dialog of Pilot-Not-Flying (PNF) – italic text
AUTOMATION VOICE – in capitals

ABBREVIATIONS:
AMU – Avionics Management Unit
AP – Autopilot
ATC – Air Traffic Control
PF – Pilot-Flying
PFD – Primary Flight Display
PNF – Pilot-Not-Flying
T/O – Take Off

NOTES:
ACTION/ MONITORING/ PLANNING (A;M;P) – For all A;M;P need a set of details on display & a special format. It could be different for each of AMP.
$$$ - IDEA
@ - THOUGHT

TO-DO:
1. Need to clean-up 'ACTIONS…' who is commanding, who is executing it. *Idea* – 'PF-PNF' means PF commands PNF to execute the action
2. Need to look over again for mode change lights - when they come ON/OFF
3. Can look for keywords to trace… ex. 'workload' ex 'I will be looking for…', 'calculation', 'mentally'.

Think of the sequence win which the checks are made to support the checklist as well to see what is most comfortable for pilots to think in terms of comfortability for them.

QUESTIONS:
Radial?

ANALYSIS of information pilot IS LOOKING FOR

Flight phase	**Pilot looking for information 'aim to hit'**	**Analysis of information needed**		**Evidence:**
Approach phase	Landing data: Threshold speed & approach speed per flap setting in REFERENCE to height & time of when to '*pull a little bit of power off*'	i.e. flap setting determines the speed, but pilot is interested in speed		(04:00) Description, like MENTAL PICTURE of what's happening '**The landing data includes** threshold speeds and approach speeds per flap setting. So if I was with 0 (zero) flap there will an approach speed & a threshold speed & what I will be looking at for are those on finals is to try and aim to hit those speeds. The approach speed I will fly all the down until I get close to the threshold & then I *pull a little bit of power off*, have the speed dribble back until I hit my threshold speed over the threshold 350ft; & then from there I pull my throttles back to flight idle & speed will decay to a touch down speed. Those speeds are already pre-calculated in the CNI & by me doing it I'm checking that they are correct, if they are not correct, we are possibly flying slower then we are required to be for that weight.'

TO DO:

1. 'MENTAL PICTURE'
   a. – shows how pilots view a particular part of the flight. (We are visual creatures, even most effective memory techniques taught are composed of visual presentation, same refers to
   b. – looking for a specific targets to 'hit'

Appendix 3

C-130J Observation Study
24/10/01 13:30
Master tape-CDcopy 3 (subject 1)
Manual

TIME LINE	SEQUENCE OF EVENTS:	DIALOG	UNDERLYING PILOT'S REFERENCE SYSTEMS	COMMENTS - DEBRIEF	GOALS:	FROM -TO		ACTION/ MONITORING/ PLANNING:	OBJECTS USED:	NOTES
03:08	TAKE-OFF briefing	'Glenfield 1 departure out of here runway 10; plate stated 4 October 2001, no amendments; gradient required 3.3%, which we can do; track 015 & 1TAC or 1000 feet, which ever is later, turn right, track 170 to intercept 144 for Richmond NDB, track to Glenfield then as cleared.' '*Copy*'	Get all	'All that is just interpreting what's on the plate there & by briefing it, it's actually putting into, right in to our minds, instead of always refer to it, some of it can be done from memory. And usually what I will do with departure, some of the departures would be quite long and complex. However, you really cannot keep all of that information in your head, so what you do is brief the first or you just remember two to three instructions, so like maintain heading 095, 1000 feet or 1 TAC. Next what I'm going to do is turn, right turn on TACAN distance. TACAN is what we use in the military – Tactical Air Navigation, type of DME. 1TAC is one DME essentially, i.e. 1 mile upwind & then make your turn onto 170. They are sort of thing I remember & without automation you can't do anything. You can't deal in 170. You can't do it, so you just got to remember it.'		PF-PNF		Looking at & reading from the departure plate		'track 015 & 1TAC or 1000 feet, ***which ever is later,*** ' – REFERENCE to TIME & SPACE
04:17	ATC T/O clearance	'Treasure 123, Glenfield 1 departure, climb & maintain 3000, clear for T/O.'				ATC-Crew				
04:23		*'Glenfield 1, 3000 clear for T/O, treasure 123'.*				PNF-ATC				
04:26		'Copy, Glendfiled 1 clear for T/O & 3000.'				PF-PNF				
04:30	ROLLING	'Crew rolling for 95 knots.'				PF-PNF				
04:42		'My controls.' *'Your controls'*	PFD	'All I'm doing is watching the runway, looking right ahead & also just quickly referencing in for the airspeed for our rotate.'		PF-PNF				
04:47	ROTATE	*'Rotate'*				PNF				
04:53		'Landing gear up.'		'All I'm looking for there on the PFD, now my focus has come in inside once we are far away from the ground. All I am doing is getting my attitude & heading set on the PFD, so		PF				REFERENCE used = limitation/flight envelope – 'over

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				I'm concentrating on putting the climb-dive marker where I want it. Obviously we don't have any reference information there now, so I am just looking at the reference, the pitch ladder. So that's all. How many degrees I want & I was looking for about 7 degrees nose up there. That's usually a good figure to remember. As accelerating at a nice rate, but not to quick, so you are not going to over speed the gear or anything like that. The other part of my scan is looking down at the compass card & quickly referencing& having a look at the level on there as to what heading I am flying.'						speed the landing gear'
05:10		*'is up.'*				PNF				
05:12		'Flaps up.'		'So this is just my side scan there. Looking at the airspeed there, making sure I have enough airspeed there, to sacrifice there, we are not stalling.' 'I command that as part of the take off checklist is pilot initiated, as oppose to the other ones which are I ask for the checklist, but co-pilot reads it.'		PF				
05:18	Passing radar (sound)					Auto-Crew				
05:21	After T/O checklist	*'Flaps up. Landing gear up, flaps up, after T/O checklist.'*				PNF-PF				

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05:28	Contacting ATC	*'Sydney approach, good day, Treasure 123, Glenfield 1 departure, passing 1000, climbing for 3000.'*				PNF-ATC				

05:35		‘Treasure 123, good afternoon. Are you tracking via Glenfield 1 departure?’ *‘Treasure 123.’*				ATC-PNF				
05:42		‘TAC1, turn right 170’		‘So in that, when I said there to myself that was just from memory. That’s what I briefed before we took off. So I knew ones we got to 1TAC that what I am going to do. That’s takes a little bit of a brain space away of trying to read the next step from your approach plate.’						
05:43		‘co-pilot, loadmaster, F-pilot.’								TIME REFERENCE – thinking ahead
05:48		*‘& there it is approaching 3000.’*				PNF-PF				
05:49		‘THOUSAND TO GO’		‘I will just explain something here. That might look like a fairly benign thing. All we are doing there just climbing & turning, but my workload is really increasing there, because I now no longer have any flight director information to tell me a rate. Like the FD works out what rate I am climbing at, when I will need to start my level off & also when I will need to start my roll out from a turn. It calculates how many degrees per second I am rolling at; how many feet per minute I am climbing at & gives me a nice solution there, so that ball eventually just comes down on to the horizon & smack-bang on my heading. Now, I mentally having to calculate all of that, so what I’m looking for. I am having a look at my rate of climb. I am doing about 2500 feet/min, so 10% of your rate of climb is what you use to level off at for your height so 250 feet before 3000 feet & that’s when I’ve got to start my level off. And they are the things I am thinking about when I am doing that. Obviously approaching about 7 degrees at the rate I was turning at – rate 1, is when you start your roll out. Ye, looks simple, but that what we do a lot of practice for instrument flying, doing coordination exercises, turning & climbing at the same time, descending & what we will do, give ourselves an arch to fly in & height bugs to fly in & you just have to keep bouncing between all of those parameters’.		Auto-Crew				**Mental calculation** the pilot has to go through, when the automation is not ON.
05:50		‘Checked.’				PF-PNF				
06:00		‘17’								
06:02		‘170’				PF-PNF				
06:09		‘Just *check your height*				PNF-				

		there'. 'Ye'				PF				
06:28		'Treasure 123, continue climbing 5000.'		'This also has a workload on PNF, because he has to monitor a lot more, because he generally has a fare bit of help from a FD & the autopilot. As well as doing all his normal task, he is constantly watching, if I haven't bust a height, an airspeed or a heading or whatever, so the workload increases significantly for both of people. It's not just the pilot.'		Atc-Crew				
06:32		'*5000, Treasure 123.'*				PNF-ATC				
06:35		'5000 is set.'				PNF-PF				
06:36		'Copy, is checked.'				PF-PNF				
06:42		'Leaving 3 for 5.' '*Good.'*		'Really the only thing that is helping me there is got to climb by ATC. Just checking that generally set the right height, above the altitude tape there, checking the cyan figure. That's a very good design issue in the PFD is the way they put all of the reference number in a different colour, that they are the same, any reference figure is all in cyan. So if you see a blue reference number anywhere, that's it. That's a reference number.'		PF-PNF				Comment of use of Colour. Pilot likes reference numbers in blue colour.
07:00		'Approaching..'				PNF-PF				
07:02		'I got the CDI (bar) coming across.'				PF-PNF				
07:05		'Altimeters'								
07:06		'Approaching 5000…								
07:07		'THOUSAND TO GO.'				Auto-Crew				
07:07		'… checked.'				PNF				
07:14		*'I can't give you a heading, because I haven't..'.* 'That's alright.'				PNF-PF				
07:30	Obtaining met conditions for destination	'Can you please give us terminal information.'				PNF-ATC				
07:32	Receiving ATIS for Sydney	'Roger, Sydney terminal information Alfa, runway 07, wind 120 degrees, 10 knots,		'My main focus now. Once I am all straight & level, just focus around the flight path marker; make sure it's around the horizon. That's it. That's why I can consider all that other staff now, because						

		QNH 1022, temperature 15, expect ILS approach.’		my workload gone to just looking at one thing now basically. As long as I have that there & make sure that the acceleration caret of the wing are not accelerating decelerating, climbing, descending.’ ‘Runway 07, that’s what I want to hear, that what we are expecting.’						
08:10		‘*Approach plate…’* ‘Yes go ahead, mate.’				PNF-PF				
08:11		*’07 finals course 06 to… starting at 3000 for finals, outer-maker check-height 1300, decision height 270, setting in the mids radar 254. Missed approach I will brief if you need it. No circling 3 knot miles DME south, sorry east of Sydney 16 Right north of runway 25…’*		‘Just checking in the Ref set panel again the brief altitudes & the approach there. That’s runway 07 at this stage, that’s right.’		PNF-PF				
08:46		‘I just hand over to you for 2 seconds, while I input my approach plate.’ *‘Sure’*				PF-PNF				
08:49		‘Handing over.’ *‘Taking over.’*				PF-PNF		PF is locating approach plate & placing it onto the yoke.		
09:00		‘Taking over.’ *‘Handing over.’*		‘At this stage all I am doing is just flying Glenfield 1 departure, so all the minor navigation aid selection up there are still the same as what I selected before take off. The only thing that will change, once we get that change of runway. You will see me manipulate that.’						
09:19	Passing radar (sound)			‘Just looking at the Nav Radar there, just to give myself a bit of orientation check. That I am where I think I am’						Pilot has a REFERENCE of himself in space & double checking with Nav Radar
09:41	Passing radar (sound)	*‘I will give you Sydney VOR DME…’*				PNF-PF				
09:45		‘Ok, Thanks mate.’								

09:48		*'428 Glenfield is in both NDBs.'*		'Navigation aid set up. What PNF was doing was just putting the other non-directional beacon across to the Glenfield frequency. Now that we were established close to Glenfield, there was no longer any need for PNF be tracking the Richmond NDB. So he was switching that across to Sydney. I was just acknowledging that & at the same time there I've got my left hand of the stick & the other one pulling the buttons on the side to identify the navigational aids into Sydney, so you can hear all the Morse code coming through.'		PNF-PF				
09:51		'All station in bound Sydney, Sydney terminal information bravo is about to be recorded duty runway 16R, switch now, 140 degrees, 15 knots, QNH 1022.'				ATC-all aircrafts				
10:09		'Treasure 123 we will make you number 3 in the sequence, turn left heading 045 to intercept the 12 mile arc for 16R ILS.'				ATC-Crew				
10:18		*'Left heading 060, to intercept 12 mile arc for ILS 16R, treasure 123.'*				PNF-ATC				
10:26		*'060'*				PNF-PF				
10:28		'I think it was 045 was he or was it us?'				PF-PNF				Lost where they were just moments ago, i.e. heading. REFERNCE needed
10:33		'Sydney, Treasure 123, just confirm that heading was 060.'		'PNF misheard what the ATC gave us. He gave us heading 045, but he read, he actually initially give us 060 & then came back again & said left heading 045 & PNF didn't respond & that's when he call him back & said, yep turn left heading 045.'		PNF-ATC				Incident of misinterpreting the heading
10:37		'Treasure 123, negative, Magnet 045.'				ATC-PNF				
10:41		'045, Treasure 123.'								
10:42		'045'		'And the reason I query that is because I had a look at the		PNF-				

				compass rose there & thought that 060 is gonna put us fairly close to the finals course there, by the time we intercept the 12 mile arc, so I thought we really need to come further left there. And that sounds reasonable to me, so I better check & that just worked out that it was what he said anyway.' What I did there on the glare shield, the first button press I did, which is just a little back from there, I highlighted one of my pointer selections there, because I knew once the runway has changed I wanted to reference the VOR to give me tracking information & needle pointer around the compass rose on the bottom, but at that point in time we did not have the VOR selected because we had the ILS frequencies in there for runway 07, so I was just waiting for PNF to swope those aids across. Once he did that you saw me there, you saw me there, I selected the VOR to give me some navigation information as to the 12-mile arc intercepting finals for 16R. Around the compass rose there Wherever the tale of the pointer is that's where you are. That's the rule you use. Once you've got that you can actually work out heading just by transposing your finger onto that compass card is to where you want to be to intercept a distance or a radial. That's sort of stuff the aircraft can't tell you.		PF				
10:48		*'And finals course RW 16R, for 155. RAD ALT.'*								
10:54		'Roger'				PF				
10:55		'Treasure 123, report airspeed.'				ATC-Crew				
10:59		*'200. Treasure 123.'*				PNF-ATC				
11:01		'Treasure 123, if you could increase to 210, thanks.'				ATC-PNF				
11:04		*'210, Treasure 123.'*				PNF-ATC				
11:10		'Copy 210 knots.' *'Copied.'* 'Turning 045.' *'Copy.'*		'Just mention something to. Just putting the power up there, obviously I'm watching the speed caret come up & go above the wing, because we want to accelerate, but as to how much that go before you get to 210 knots it's something that I had to constantly monitor, once I got to 210 knots, then I had to pull power back make sure the caret was on the wing. So it didn't raise the workload a great deal, but it did a little bit.		PF-PNF				@ TIME REFERENCE of the future, present, past - is already can be observed in the cockpit – speed caret, i.e. goes up when

				There is nothing that really tells you after 210 knots at this height you need to set this power.’						accelerating & down decelerating
11:16		‘*212 NDR MINIMUS radar set to 212. Outermarker check height 1295 at 4.7 I’ll give you localiser frequency when you are turning. Approaching the lead radial there.’* ‘OK’				PNF-PF		Selecting VOR	AMU panel	
11:35		‘Treasure 123. We saw you through 12 mile arc there, if you could turn left there, intercept the arc through 16R ILS’				ATC-crew				
11:42		‘*Turning left intercept 12 mile arc. Treasure 123.*’				PNF-ATC				
11:50		‘Not by much there.’ ‘*No*’		‘ATC being a little picky with this 12 mile arc. I was at 11 miles, the tolerance of the side of that & DME is 2 miles, so we were still within tolerance there, but he obviously wanted us right on the 12 mile arc. I thought I have already done it, but that’s when I selected the VOR. That’s the time to set the VOR.’ *What is the 111?* ‘111 is in the IAS slot - what our obstacle clearance speed was… And that stays there all the time unless you change it or connect an Autothrottle. That’s the only time its ever changes.’						
12:22		‘Sorry, the lead radial was there again?’ ‘*323.*’ ‘323 roger.’		‘I use the tip of that needle to give me an orientation, as to tell me, am I getting further away from the NAV aid or closer to it, so that’s how I am adjusting my 12 nautical ark there. Because that needle gone above the line, what I am doing is flying away from the station to increase my distance from it.’		PF-PNF				
12:26		‘*It’s our final course there in the box there.’* ‘Ok. Thanks.’				PNF-PF				
12:38		‘Ok, that’s coming up toward the 12milish arc.’				PF-PNF				

12:42		‘We were still within track 2 knots when they gave us there’ ‘*Ye*’				PF-PNF				
12:52		‘Treasure 123 descent to 3000.’				ATC-Crew				
12:54		*‘3000, left 5000. Treasure 123’*		‘The ATC gave us descend down to 3000, which is the starting height from which you make the approach, so that’s something we **were expecting** to come up soon anyway. The ATC basically told me to maintain 12 mile arc better, so the workload is still on me to adjust my heading to keep that 12 mile arc pretty much on 12 miles.’		PNF-ATC				Pilots have a plan of sequence of events – ‘we **were expecting** to come up anyway’
12:58		‘and copy. *3000, left 5000.*’				PF-PNF				
13:13		‘ok, go across to the ILS, that’s fine mate.’				PF-PNF				
13:16		*‘and I will put in your.’*		‘Now that I’m happy & established on the 12 mile arc, I don’t really need the tail of the needle any more & that’s why PNF was taking the frequency to the ILS frequency for the azimuth on the ILS now. Azimuth is that going left or right of the centreline.’		PNF-PF				
13:23	Morse code identification – radar navigation									
13:28		*‘and Altimeters.’*				PNF-PF				
13:30		‘and approaching 3000.’ ‘*Good*’								
13:35		*’2 to 12, miles’*				PNF-PF				
13:37		‘yep’								
13:40		‘THOUSAND TO GO’				Auto-Crew				
13:40		‘Treasure 123, you can cancel speed restriction. You are cleared 16R for the ILS. Once established on finals contact tower 120,5.’				ATC-Crew				
13:47		*‘Cleared for the ILS*		‘He (ATC) cancelled the speed restriction from 210 knots, so		PNF-				

		16R. Cancel speed restriction. Tower 120,5 once established. Treasure 123.'		I can fly whatever I want to fly, where last time I decided to do that anyway, because we were getting close.' 'So even though I'm descending you can see, the airspeed, the energy caret is below the wing this means we are decelerating.'		ATC				
14:05	'*BIP-BIP*' - annunciation									
14:11		'We can come back to 170 now, so we can…'. *'Copied.'*				PF-PNF				
14:27		*'Loose a bit of speed in a turn too so that we get us there later.'*				PNF-PF				
14:32		'VOR, alright, I will put TACAN1 on that to add some distance there.' '*Yep.*'		'(*Checking*) that I've got all the right selection there, the one I turn on to the ILS. I'm checking that on the CDI bar I've got the ILS frequency selected. So VOR is my CDI selection, pointer 1 is TACAN & pointer 2 is TACAN. And again TACAN means DME, so that I can have a reference to the outermarker check-height, when I am likely to incept the glide slope. So things I look for that is, just as a check I always calculate, when I am going to intercept my glide slope, because my style is designed to enter a 3-degree slope, you can calculate that every mile you need to be 300 feet. So at 5 miles out I should be 1 500 feet, 10 miles out I should be 3000 feet. We are at 3000 feet, so we were going to intercept the glide slope at 10 miles. So I was just referencing down to the distance there at the bottom of the PFD to give me an indication so as to when I was going to intercept the finals course in the glide slope.'				Checking & touching the AMU panel		How Pilots remember what they select as what in there nav aids? – to explore Calculation of the 3 degree slope = 300 feet/mile (at speed of 200knots)
14:39		'And go ahead with the landing checklist.' *'Flaps'*. 'Below 180, flaps 50.' 'Copied.'								
14:45		'Got the floater starting to come there now, so.'				PF-PNF			?? floater??	
14:51		*'Flaps are 50 now. Landing gear.'* 'Below 160 landing gear down.'		'So all I'm concentrating on here. In fact there are quite a few things I am concentrating on here. Making sure I am staying level, because I can't leave 3000 feet until I intercept that glide slope & I am established within tolerances for the approach. The other thing I am looking for my airspeed to be decreasing, now so that we can get the landing gear down, but not keep washing the speed off. Also I'm watching the						**Picture in mind** of a Pilot - FORWARD THINKING

				compass card & seeing that the Course Deviation Indicator (CDI) which is that bar in the center of that white thing to intercept my correct azimuth there. So I am watching about 3 to 4 different things here at the moment.'						
15:14		*'Landing gear down. Three green.'*				PNF-PF				
15:17		'Down, three greens'				PF-PNF				
15:18		*' panel set.'*				PNF				
15:20		'*Landing checks.'*				Crew				
15:23		'Pilot, *co-pilot*, load-***master***.'				Crew				
15:27		'*Sydney Tower good day, Treasure 123. Established ILS finals on 16R, three greens.'*				PNF-ATC				
15:33		'Treasure 123, Good morning, Sydney Tower, continue the approach, reporting an outermarker.'				ATC-Crew				
15:38		*'Ok, Treasure 123.'*								
15:40		'We should expect an intercept in about 10 miles, there on the glide slope. '		'That's what I was telling you before. I calculated that in my head. Pretty much as you see 10 miles click over, glide slope right in the center. Ready to go.'		PF-PNF				
15:46		*'Quite close in.'*				PNF				
15:49		'And leaving 3000 for the minimum of 220.'				PF-PNF				
15:54		*'And checked'*								
15:56		*'Beacon button is pulled.'*				PNF-PF				
15:58		'Likewise.'				PF-PNF				
16:10		'CHECK ALTITUDE'				Auto-Crew				
16:13		'Just wind that out, thanks mate.'		'That little indication you got there (across top of PFD) is, because we deviated more then 200 feet from the set altitude, which was 3000 at the time. It was letting us know that we where not on the altitude that we had set. We didn't need to be, because we were on glideslope & we were cleared to descend. So what we normally do, just wind that up & outside the window that is sets it off at, so it doesn't keep		PF-PNF				

				saying ‘Altitude, Altitude’. It’s really annoying.’ ‘Certainly, you should, but because we all know we are established in the approach. It’s one of those things that you do ignore it.’						
16:20		*‘Outer maker set at 4.7.’*				PNF-PF				
16:26		‘Course 95’		‘So what I am concentrating on there now, because I don’t have a Flight Director. I have to scan between the little glideslope indicator on the left hand side there & the CDI bar in the center. And that’s what I am doing; I am just manipulating those now. I am looking at my rate of descent on the side, which is that little white arrow that comes up & down. And what I am aiming for is about 700 foot/min rate of descend. And if I keep that on my air speed of 140 knots I know that I will stay on Glideslope. That’s just something you know about the aircraft. That’s how it performs. And then if I maintain that, that’s less time that I have to scan to that Glideslope indicator on the side there. And then what I really have to worry about is maintaining the left & right on the Azimuth. As you can see that, it’s sort of goes all over the place. You can’t do as good as the computer.’ And also **the indications you have on the PFD there are not as accurate as having the FD there**, because it takes longer for your eye to pick up the movement of that bar a little bit of centreline rather then the circle going left or right. If you see that circle going left or right you almost immediately move left or right to capture that again, but with that CDI there down the bottom you have to look over the control column a bit. It’s obscured. It’s a little further away. Not as well annunciate, so that’s why you get a few more inaccuracies in your flying. But we also another information there. There is a little cross, which sits on the top of the compass rose there & that gives us a tracking information. So what’s that doing is the inertia navigation system going, ‘ok, we’ve got this much wind it’s 10 knots from the left, there for we are drifting right. So to maintain your track, you need to come left of your heading by 5 degrees & that’s what little cross tells you to do. So once I centralise that bar, next thing I look for is getting that cross on the tip of the needle. Once I’ve done that I know that bar is not going to move any more. And that’s something I was letting out of my scan. Something I‘m not use to doing on PFD.		PF-PNF				Display problems… *‘the indications on the PFD there are not as accurate as the FD’*

				You've got to look at 3 Glideslope the middle & the cross, plus the Climb Dive Marker (CDM), plus the rate of descent, plus airspeed. So there are about 5 or 6 things to scan there. 'If you had a FD there, let me count that the… it's basically 4 of those things will not have to scan. So it's a the CDI bar, because it gives you left & right; drift, because the INS input goes through FD to give you left or right. So it will not only give you the information as to how to capture the CDI bar again, but how to maintain it centrally. It will also give you the information on your Glideslope. So that's Glideslope, CDI, tracking & rate of descent will give you all in that one. So very nice.						
17:55		BIP, BIP, BIP…..		Right now, I am interested in getting a landing clearance, so I am waiting for that come through. I am also, next thing I'm looking at validating the ILS by that outermarker check height again. And PNF briefed a little bit before, as to what the height, distance we were looking for, so that's a next step.' 'I'm looking outside trying to pick up the visual environment again, but mainly still just referring to those things I was scanning, CDI bar, Glideslope, rate of descent, Climb Dive marker, airspeed.' 'So it's all an internal scan on the PFD there. I am not looking at anything else.' 'There is an outermarker. Yes, it gives you the height if you are on Glideslope at that point. You should be at this height there. I take a quick glance across at the altimeter. Once we are at 4.7 DME, we are directly over the outermarker there & if that height is high. It means that & on Glideslope. It means my altimeter is out a bit. So I make an altimeter correction on my MINIMA. So instead of it being 220, so if I was high on the outemarker check height by 50 feet, I would raise that MINIMA to 270, but if I am low on it, I don't need to raise it. So once we go through it, you will see me say, 'Low good to go', that's just general phrase we use.'		Auto-Crew				Pilot's timeline expectations – '*waiting for…*'
18:05		'4.7 there.'				PF-PNF				
18:11		'4.7, 1295, Outer marker height checked.'								
18:12		*'Co-pilot is visual.'*				PNF-PF				
18:15		'And likewise, I will				PF-				

		just continue down on the glide slope there.' *'Ok.'*				PNF				
18:31		*'coming 21 for 116.'*								
18:35		'And checks.'		'Checking my landing speed there. Now you can see my head starting to look out more. Starting to establish the visual environment, the aspect of the runway & marry that up to what I am seeing on the instrumentation there.'		PF-PNF		Looking at CNI for a landing speed		
18:55		'Treasure 123, you could land, check your gear.'				ATC-Crew				
18:58		*'Land, three green. Treasure 123.'*				PNF-ATC				
19:00		'Copy, clear to land. The runway appear clear and below 145, flaps 100, thanks.'				PF-NF				
19:05		*'117 for 107.'* 'Checks.'								
19:10		*'Flaps 100.'*		'Looking that the flap indicator. There is a little flap indicator below the engine display there.'		PNF-PF				
19:23		*'6 knots from the left.'* 'Roger.'								
19:25		*'8 knots from the left.'*								
19:36		'MINIMUS, MINIMUS.'				Auto-Crew				
19:37		'GLIDESLOPE, GLI-GLIDESLOPE, GLIDESLOPE'		''What happen there, I look out for a bit too long & then what I've done I flown into the edge of tolerance area the Ground Collision Avoidance System & what it will do, it will let you know that you are off your glideslope. And that's quite important because if the weather was fairly marginal there & we had the minimal visibility there & that was at night, there is a lot of optical illusion you can get & by having not so bright lights there, you tend to fly towards the lights & that's the thing that's build into the system, that stops you from doing that. So as soon as you go out of that small tolerance area towards the end of the Glideslope it will let you know, so that you go, 'Ups, hang on, I am flying a bit low there, because it's very easy to get trapped with flying below the Glideslope. You do like a little dive towards the end there. Ye, it's usually an illusion with the lights.' Because it was during the day, I didn't worry about it too		Auto-Crew				

				much. I just pulled up a little bit & made the moaning go away.'						
20:05	LAND			'Ye, all outside now. I took my last look at the airspeed, just make sure I've got what I want. There is a touch down.' 'Now, all I am worried about is to keep that centreline right in the middle, as close to it.						
20:12		'Your controls.' *'My controls'*								
				'Definitely the value of the FD, that's the first thing you miss, so having to think of those manual things; what sort of margins you have to anticipate – level off, turning on heading. That sort of thing. Manually thinking, where you are with regards to navigation aids & just things like that increase the workload slightly on flying pilot & to a certain extend on the PNF; detracts a little bit from the normal procedures that you do. Just increase the workload a little bit. Also for your personal pride I guess, your flying is not quite as accurate as to what it can be. Using the automation give you other cues, which you are use to.						
				(if you can change anything … what would it be) That I wouldn't really change much. Obviously, we were in the sim for the second time, we've already seen the scenario, so we where expecting a few different things, that we were not at the time before. We were quite comfortable with what was happening & I guess in that way it gives you a great advantage so I really thought there is not much that I would do differently there. In fact I don't think there is anything really I would do differently. Everything was flown within tolerances. It was completely safe & it was done using Standard Operating procedures. And we trained to that standard, just in case we don't have FD or we don't have the automation. We've got to be able to do that. It's part of our requirements, so I wouldn't change anything, no.						
				''The main things with flying heads down & flying with manual data is you begin to fixate on things. The main thing to do is to tell them to do is increase your scan rate, which is the hard thing to do, because the only way you can do it by doing this sort of things. So ye, just increase your scan rate around the instrumentation & the information that you've got. And remember basic techniques, because what I just did there, I learned on pilot's course that what they taught me. I just applied to C130J. If I flew another type of aircraft I						

				would applying to another aircraft type, so realistically that standard you should be able to expect from anyone who is flying this type of aircraft, whether a co-pilot or a captain.						
				There is a lot of information on that PFD. I am actually the other way around; I’ve got very little of EFIS time. I’ve spent most of my time on quite an archaic aircraft type. I did 250 hours on PC9s, which is an EFIS set up. Then for about 5 years I did not flying on EFIS aircraft. I flew C130E, so I flew heads down & just visually, just like I did on this one, but instrumentation we had was all analog dials, everything was dials. All the engines displays were dials, there was nothing in there that would help you. We did have the FD. They were bard & they would move around like that floating bars, so the quality of the FD presentation was not as good as what they have with this. So when I came from that background to an aircraft that was such a great EFIS set-up as this. It was information overload for the first part of						

~ event can occur any time
event - it indicates start & finish of the task
Dialog of Pilot Flying (PF) – straight text
Dialog of Pilot-Not-Flying (PNF) – italic text
AUTOMATION VOICE – in capitals
Interesting incident

ABBREVIATIONS:
AMU – Avionics Management Unit
AP – Autopilot
ATC – Air Traffic Control
CDI - Course Deviation Indicator
INS – Inertia Navigation System
PF – Pilot-Flying
PFD – Primary Flight Display
PNF – Pilot-Not-Flying
T/O – Take Off